# AGRICULTURAL ENGINEERING

The Journal of the American Society of Agricultural Engineers

FEBRUARY 1934

In this issue of AGRICULTURAL ENGINEERING will be found, for the purpose of detailed study and correlation, the 1933 results of experience and experimentation with soft rubber tires for farm tractors and other equipment, from 14 states in widely separated sections of the United States and from one Canadian province. This material constitutes the most up-to-date and authoritative data available on the progress and status of development of rubber tire applications for agricultural machinery.

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# AGRICULTURAL ENGINEERING

Published by the AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS, St. Joseph, Michigan

Publication Office, Benton Harbor, Michigan. Editorial and Advertising Departments, St. Joseph, Michigan

ARTHUR HUNTINGTON, PRESIDENT RAYMOND OLNEY, SECRETARY-TREASURER

Volume 15 FEBRUARY 1934 Number 2

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Subscription price to non-members of the Society, $3.00 a year, 30 cents a copy; to members of the Society, $2.00 a year. Postage to countries to which second-class rates do not apply, $1.00 additional. Entered as second-class matter, October 28, 1933, at the post office at Benton Harbor, Michigan, under the Act of August 24, 1912. Additional entry at St. Joseph, Michigan. Acceptance for mailing at the special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized August 11, 1921. The title AGRICULTURAL ENGINEERING is registered in the U. S. Patent Office.

# AGRICULTURAL ENGINEERING

Volume 15 FEBRUARY 1934 Number 2


# A Comparative Study of Pneumatic Tires and Steel Wheels on Farm Tractors[1]


By C. W. Smith[2] and Lloyd W. Hurlbut[3]


DURING THE SUMMER of 1932 the Agricultural Engineering Department of the University of Nebraska became interested in the use of pneumatic tires on farm tractors. A study of the problem was carried on through the fall, winter, and spring, the results of which were reported to this Society at its 1933 annual meeting at Purdue University in June by Mr. Hurlbut. On June 9, 1933, an enlarged plan for studying the problem was set up, this being made possible by the cooperation of four rubber companies: The Firestone Tire & Rubber Co., the B. F. Goodrich Co., the Goodyear Tire & Rubber Co., and the United States Tire Co. A progress report of this work was given by C. W. Smith at the International Automotive Engineers' Congress of the Society of Automotive Engineers at Chicago on August 30, 1933. The work covered since presenting that report in August has been a continuation of the plans made last June.

Tests Nos. 1 to 15, inclusive, and the study of travel reduction as affected by tire inflation pressure, drawbar pull and tractor speed, are essentially the same material as presented at the S.A.E. meeting in August. Some drawbar pull travel reduction data from the tractor testing course was taken from that reported in June to this Society, for comparison with maximum drawbar pull and travel reduction data secured later in a stubble field. All other material is being presented for the first time in this paper.

The goal set up when plans were made in June was that two tractors of the same make and model should be run in the same field at the same time, each pulling as nearly as possible identical loads, one tractor being equipped with pneumatic tires and the other with steel wheels and spade lugs. When half the work had been finished, the wheel equipment was to be interchanged on the tractors and then the remaining half of the work finished with the tractors thus equipped. In that way, comparable data could be secured under identically the same weather conditions for two similar tractors and also comparable data for the same tractor and two types of wheel equipment in as short a space of time as possible. This goal, as originally set up, was kept in mind and plans made accordingly as far as possible throughout the work, but in several instances circumstances arose which made it advisable to report the data as two separate tests instead of as one. To illustrate this, two examples will be given.


A plowing test was planned with a field of approximately 20 acres of alfalfa sod, two Allis-Chalmers Model "U" tractors and two three-bottom plows. The field was carefully divided into four equal lands so that each tractor would have one land for steel wheels and one land for rubber tires. Preliminary arrangements, such as assembling the equipment, making plow adjustments, and getting moldboards to scour, had taken more than one day. All such preparations having been completed, the tractors were started off on their respective lands at approximately the same time. No sooner had a couple of rounds been made than it could be seen that high speed was too fast for the land being plowed with rubber tires, although the tractor could handle the load almost as well in high as in intermediate. A strip of bluegrass sod had worked its way out into this land and, when plowed in high, the sod rolled completely over, landing right side up. This made it necessary to complete this land in intermediate gear although the data were wanted in high, if within the power of the tractor to go in high. On the other land plowed with rubber tires, it was possible to travel in high and do a good job of plowing. This was done, and it was not deemed advisable to average the rubber tire data. Therefore, the data are reported as two tests, each with one tractor, although taken in the same field at the same time.

Another instance is the data reported as tests Nos. 23 and 24. Two Farmall tractors of about the same age and

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[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers at The Stevens, Chicago, December 1933.

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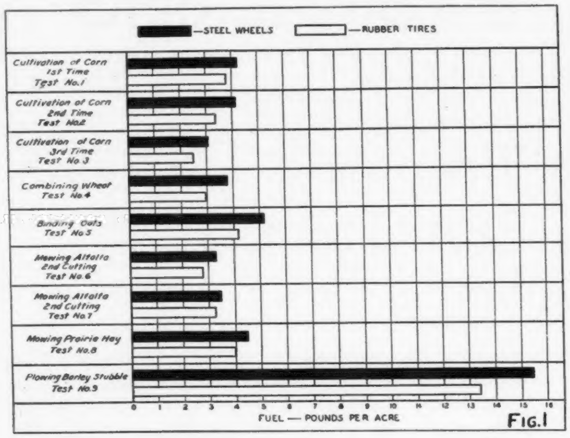


FIG. 1

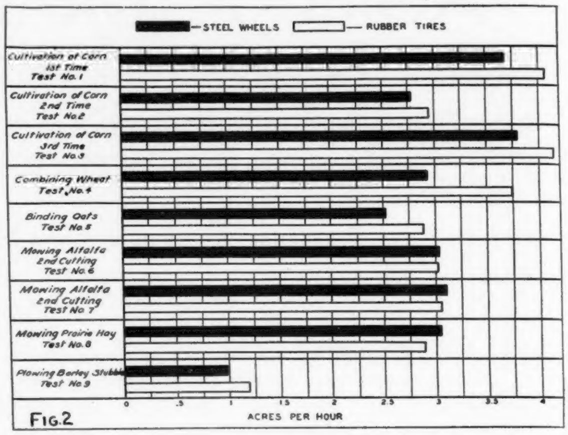


FIG. 2

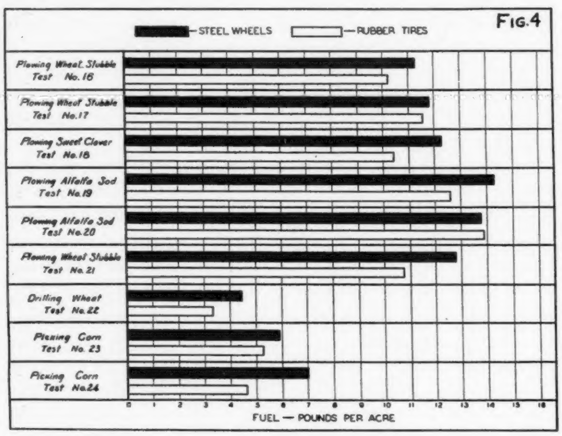


FIG. 4

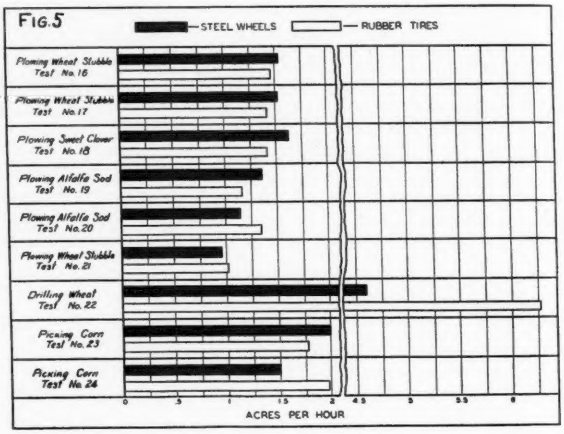


FIG. 5

general appearance were secured. Plans mapped out and both outfits started. The tractor with steel wheels could not pull the corn picker and wagon in intermediate gear so was driven in low gear. However, the other tractor, when equipped with steel wheels, could pull the load in intermediate gear and did throughout the test, with the exception of a few short shifts into low gear. Since one tractor ran in low gear and the other in intermediate gear when equipped with steel, it seemed advisable not to average the data but to report as two separate tests although run in the same field at the same time.

To arrange field tests of the magnitude necessitated by such an ambitious plan as was mapped out in June required a considerable amount of scouting over a large territory. Briefly, the operations reported in this paper extended from 115 miles southwest and 120 miles northwest of Lincoln, Nebraska, to 95 miles east of the same city.

We used and compared the pneumatic tires with steel wheels on the following farm operations:

1 Cultivating listed corn the first time over
2 Cultivating listed corn the second time over
3 Cultivating listed corn the third time over
4 Mowing alfalfa hay
5 Mowing wild prairie hay
6 Sweeping alfalfa hay
7 Sweeping wild prairie hay
8 Binding oats
9 Combining wheat
10 Plowing barley stubble
11 Plowing wheat stubble
12 Plowing sweet clover
13 Plowing alfalfa sod
14 Drilling wheat
15 Picking corn.

Our data from the above-named operations have been tabulated as 24 tests. Tests Nos. 1 to 9, inclusive, are graphically shown in Figs. 1 and 2, and are those tests which lend themselves to an analysis both of the fuel in pounds per acre and to the acres per hour. They conformed to a conventional procedure of the region in which they were carried on, and no irregularities occurred while they were being made that would make them incomplete or in need of accompanying comments.

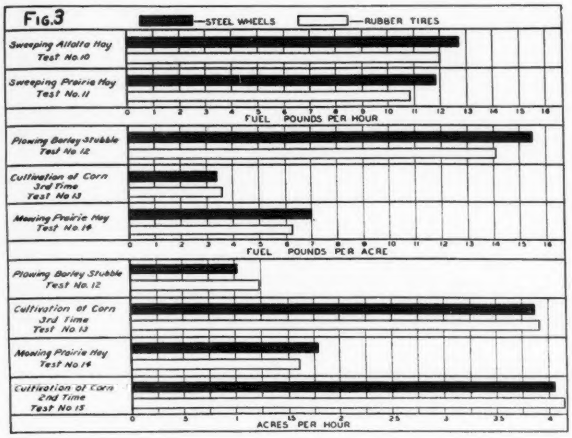
Tests 10 to 15, inclusive, are shown in Fig. 3 and are irregular in some respect when viewed from all angles designated in the preceding paragraph. Several of them are fully as valuable as those listed in Figs. 1 and 2.

Test No. 10. Sweeping alfalfa hay is a farm operation on which it was impractical for us to attempt to get acres per hour or tons per hour. The data reported need no apology.

Test No. 11. Sweeping prairie hay is irregular for the same reasons as given for test No. 10.

Test No. 12. Plowing barley stubble was listed among the irregular tests because it was made with lug chains on the pneumatic tires. The data are first class in every respect.

Test No. 13. Cultivating corn the third time over was irregular in that this tractor could not pull the three-row




FIGS. 1 AND 2 A COMPARISON OF PNEUMATIC-TIRED TRACTORS WITH THOSE HAVING STEEL WHEELS AND LUGS IN FUEL CONSUMPTION AND IN ACRES PER HOUR AS SHOWN BY NINE TESTS

FIG. 3 A COMPARISON OF TRACTORS HAVING PNEUMATIC TIRES WITH THOSE EQUIPPED WITH STEEL WHEELS AND LUGS IN FUEL CONSUMPTION AND ACRES COVERED PER HOUR, AS SHOWN BY SIX TESTS

FIGS. 4 AND 5 A COMPARISON OF PNEUMATIC-TIRED TRACTORS WITH THOSE HAVING STEEL WHEELS AND LUGS IN FUEL CONSUMPTION AND ACRES COVERED PER HOUR AS SHOWN BY NINE TESTS

cultivator in high gear with steel wheels but did pull it in high with the rubber tires. It was our judgment that this particular tractor was overloaded when travelling in high gear.

Test No. 14. Mowing prairie hay was irregular in that the meadows was so rough that it was deemed good judgment to travel in intermediate gear. The customary procedure is to mow in high gear. All other mowing tests reported were made in high gear. In this test, time was taken to make square, clean corners.

Test No. 15. Cultivation of corn the second time over was considered irregular because an unavoidable delay made is impossible to make a change of wheel equipment and, therefore, the fuel consumption of the two tractors could not be compared. The acres per hour as reported in this test carry no reservations.

Consider these tests one at a time and in the order in which they are numbered:

Test No. 1, cultivating corn the first time over, was made with one Farmall 30 and a four-row cultivator for listed corn. Steel wheels with skid rims were used in front, both when steel wheels and 5-in spade lugs were used on the rear, and also when 11.25 x 24-in pneumatic tires were used on the rear. Two wheel weights were used on each rear wheel when pneumatic tires were used. The land was rolling and the soil was a silt loam. The speed of the tractor was less in any one gear with these rubber tires than with steel wheels. But in this case it was possible to drive the tractor in high gear with the rubber tires where intermediate gear had to be used with the steel wheels and lugs. The tractor, when equipped with rubber tires, used 88.95 per cent as many pounds of fuel per acre and covered 110.31 per cent as many acres per hour. The tractor equipped with rubber tires was harder to keep on the lister ridges than with the steel wheels and lugs. Part of this difficulty was due to the fact that the tread of the rear wheels was widened by over eleven inches when the rubber-tired wheels were installed, and this made them run on the outer portion of the ridges instead of on the centers as the steel wheels did. There was less dust about the tractor and operator when the rubber tires were being used.

Test No. 2, cultivation of corn the second time over, is the average of three runs made with two Farmall tractors, each equipped with International two-row cultivators, both outfits running simultaneously side by side, one tractor being equipped with 9 x 36 pneumatic tires and two wheel weights per wheel, the other with steel wheels and lugs for approximately one-half the time of the test. Then the wheel equipment was interchanged on the tractors, and the work continued through the second half of the runs. The third run used in this average was made with one of the above-mentioned Farmall 20 tractors in another field, the tractor being equipped approximately half the time with pneumatic tires and half the time with steel wheels and lugs. The tractors when equipped with rubber tires used 80.9 per cent as many pounds of fuel per acre and covered 106.24 per cent as many acres per hour, as the tractors when equipped with steel wheels and lugs did. There was less dust about the tractor and operator while the pneumatic tires were being used. The soil was a silt loam and it was quite dry: one field was level; one was rolling. The pneumatic tires left a track in the first field which would have been detrimental had there been more moisture in the soil. A set of sweeps or duck feet was installed for the work in the second field, and they defaced the track completely.

### Less Field Dust When Using Rubber Tires

Test No. 3, cultivation of corn the third time over, gives data secured from one John Deere general-purpose tractor and a three-row John Deere cultivator, run first on 11.25 x 24 rubber tires with two wheel weights per rear wheel, and then on steel wheels by the same man in the same field and on the same day. The tractor was run in high gear with both types of wheel equipment. The plan had been to run two similar outfits simultaneously, and this was done. One tractor had seen more service than the other and was unable to travel in high with the cultivator when equipped with steel wheels and lugs. It did, however, travel in high speed with rubber tires. It was our judgment that this tractor was overloaded in high, and therefore we used the data from it for test No. 13. From test No. 3 we see that the rubber-tired tractor used 82.1 per cent as many pounds of fuel per acre and covered 109.24 per cent as many acres per hour as the tractor when equipped with steel wheels and spade lugs. In all cultivating tests with John Deere equipment as well as Farmall equipment, steel wheels with skid bands were used in front. The rubber-equipped tractor rode easier and handled as easily as the tractor with steel wheels and lugs. There was less dust about the tractor and operator when rubber tires were used. The ground, largely level, was a black silt loam. The John Deere standard equipment on the three-row cultivator obliterates the wheel tracks completely.

Test No. 4, combining wheat, comprises data secured from one Farmall tractor pulling a 12-ft International harvester-thresher in wheat, making about 25 bu to the acre and having a heavy growth of straw. The outfit was run one afternoon with steel wheels and lugs, and the following afternoon with 11.25 x 24 rubber tires and two weights per wheel. No change in field conditions had occurred between the two tests, except that the field was smaller and the rubber tires were handicapped a bit by having more turning. While the steel wheel and lug equipment was being used, it was necessary to run the tractor in low gear;

with the rubber equipment it was run in intermediate gear and throttled when necessary. The field was almost perfectly level and the soil is classified as a sandy clay loam.

The tractor when equipped with rubber used 78 per cent as much fuel per acre and covered 127.61 per cent as many acres per hour as when equipped with steel wheels and lugs. The driver was delighted with the manner in which the tractor handled. Steel wheels were used in front throughout the entire test.

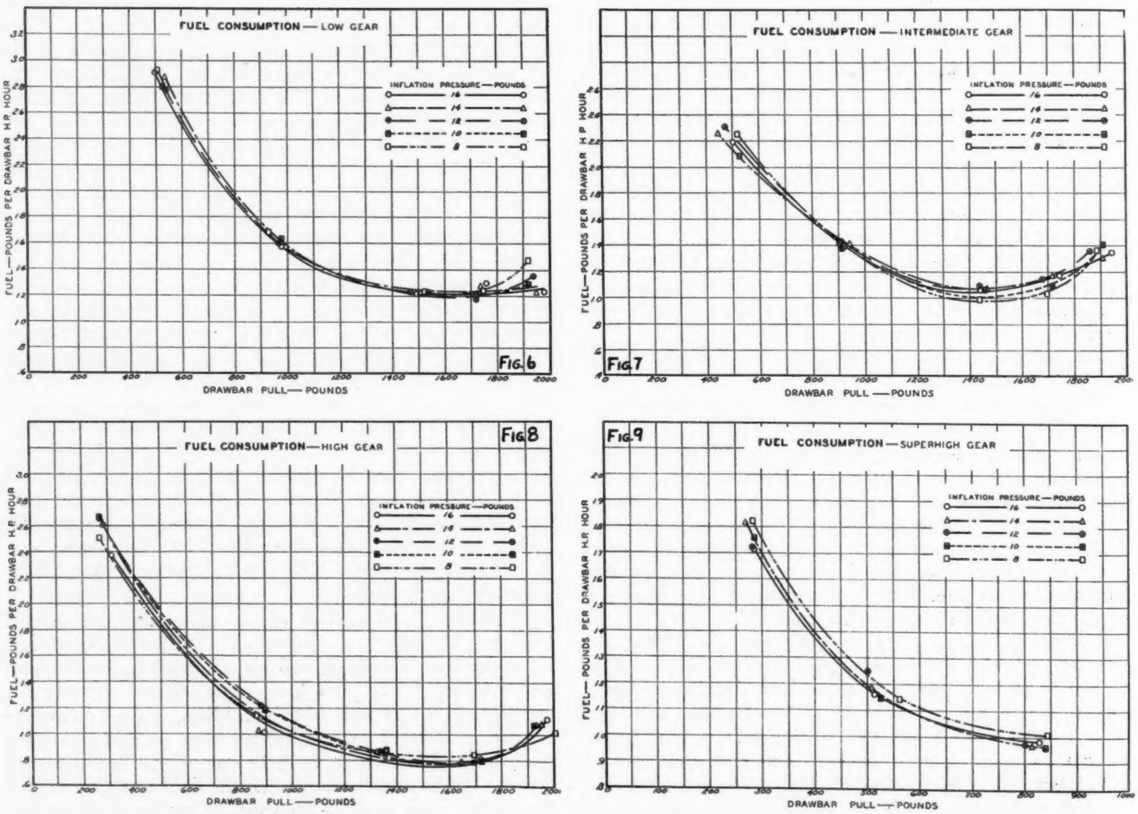
Test No. 5, binding oats, was secured with one Farmall 20 on a 7-ft ground-drive binder. The tractor was first run with steel wheel and lug equipment, then with rubber, and again with steel. The ground was rolling and the oats short, light, and a little greener than when usually cut. The tractor was driven in intermediate gear throughout the test. When equipped with rubber tires the tractor used 80.7 per cent as many pounds of fuel per acre and covered 114.22 per cent as many acres per hour as when equipped with steel wheels and lugs. The soil was a silt loam. Steel wheels with skid rims were used in front at all times. The rubber tires for the rear were 9.00 x 36. There were two wheel weights on each rear wheel, while rubber was being used.

Test No. 6, mowing the second cutting of alfalfa, was secured by running two Farmalls simultaneously with power mowers while cutting about 30 acres, and then using only one Farmall on a second field where 15 acres were cut. While two tractors were being used, the same procedure relative to changing wheel equipment was followed as has been described before. Two wheel weights on each rear wheel were used. A set of 9.00 x 36 pneumatic tires were used on the rear; steel wheels in front. The rubber-tired tractor used 85.14 per cent as many pounds of fuel per acre and covered 94.73 per cent as many acres per hour as the tractor with steel wheels and lugs. The rubber tires having a wider tread made it hard to cut the full width of the sickle bar.

Test No. 7, mowing the second cutting of alfalfa, was secured with two John Deere general-purpose tractors and John Deere 7-ft power mowers. The pneumatic tires used on the rear were 11.25 x 24, while 6.00 x 16 tires were used in front. It was the custom of the man who owned the alfalfa ground to use his tractor with no skid bands in front and no lugs on the rear wheels for all of his haying operations. The rubber-tire equipment was compared with the bare steel wheels in this test. The rubber-tired tractor used 94.35 per cent as many pounds of fuel per acre and covered 98.55 per cent as many acres per hour. The rubber-tired tractor was much easier riding. Both tractors were driven in high gear.

Test No. 8, mowing prairie hay, was secured by using two John Deere general-purpose tractors and two John Deere power mowers. A set of 11.25x24 pneumatic tires were used in the rear and 6.00 x 16 pneumatic tires in front. Two weights were used on each rear wheel when equipped with rubber.

The tractors were driven in high gear, and the corners were taken without releasing the clutch. The rubber-tired tractor used 88.61 per cent as many pounds of fuel per acre and covered 95.05 per cent as many acres per hour as




FIGS. 6, 7, 8, AND 9 THE RELATIONSHIP OF FUEL CONSUMPTION IN POUNDS PER DRAWBAR HORSEPOWER HOUR TO DRAWBAR PULL IN POUNDS FOR FIVE TIRE INFLATION PRESSURES

TWO VIEWS OF TESTING EQUIPMENT USED IN THE NEBRASKA PNEUMATIC TIRE STUDY

the steel-wheeled tractor. The rubber-tired tractor was easier riding and could make much better corners than the one equipped with steel. The skid rings on the front wheels of the tractor equipped with steel prevented the front end from swinging as squarely around on corners as would the tractor equipped with rubber tires. The steel lugs poked hay into the ground which was objectionable. Each steel wheel on the rear had one row of twenty-four 5-in spade lugs.

Test No. 9, plowing barley stubble, was secured with two John Deere general-purpose tractors, one equipped with steel wheels; skid rings in front and 5-in spade lugs behind; the other with pneumatic tires, 6.00 x 16 in front and 11.25 x 24 behind. Wheel equipment was not changed on this test. Fuel consumption was corrected according to the fuel consumption characteristics of the two tractors, which were known at the time this test was made. The rubber-tired tractor traveled in high gear with a two-bottom plow where the steel-wheeled tractor was compelled to travel in intermediate. The rubber-tired tractor used 87.14 per cent as much fuel per acre and covered 125.69 per cent as many acres per hour. The rubber-tired tractor was easier riding. The inflation pressure of the front tires was 26 lb, and with this pressure one tractor was as easy to steer as the other. The tread having been widened when rubber was installed made the rear furrow wheel run on some of the loose dirt instead of directly on the bottom of the furrow. Two weights were used on each drivewheel when equipped with rubber.

## Rubber Tires Render Good Service in "Sweeping" Hay

Test No. 10, sweeping alfalfa hay, was secured with two John Deere general-purpose tractors and two John Deere tractor sweeps. One tractor was equipped with smooth steel wheels in front and in the rear. The other tractor was equipped with 6.00 x 16 pneumatic tires in front and 11.25 x 24 pneumatic tires in the rear. No wheel weights were added to the rear wheels equipped with pneumatic tires. Approximately half the sweeping was done with the tractors thus equipped. Then the wheel equipment was changed on the tractors and the remainder of the sweeping completed. We tried to load both sweeps heavily, but owing to the limitation in traction of the smooth steel wheels, the rubber-tired tractors moved more hay. The rubber-tired tractors used 94.12 per cent as many pounds of fuel per hour as the steel-wheeled tractors. Had they moved equal amounts of hay, the results would have shown a greater advantage in fuel consumption for the rubber-tired tractors. It was impossible to turn around within a reasonable distance with a large sweep load of hay when the pressure in the front pneumatic tires was 15 lb. Raising the pressure to 26 lb made steering quite satisfactory. The pneumatic tires gave splendid service in this work and showed to have advantages in several respects over steel-wheel equipment. First, they were easier riding. Second, they had much better traction than the smooth, steel wheels. They steered better than the steel-wheeled tractor. Both tractors traveled in high gear.

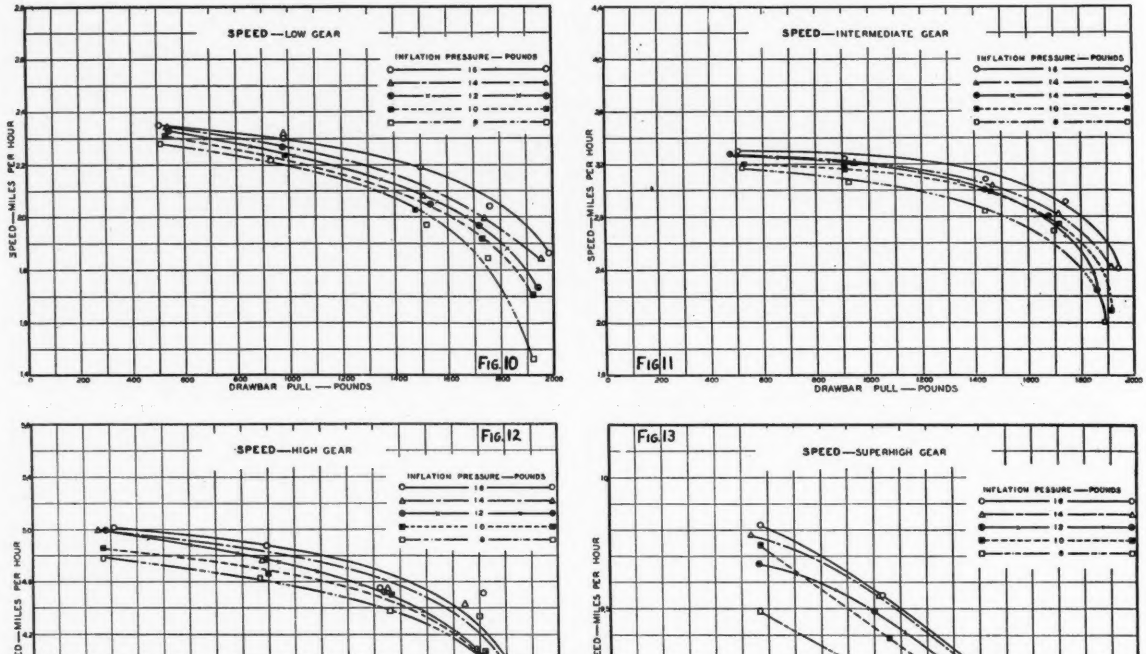
Test No. 11, sweeping prairie hay, was secured with two John Deere general-purpose tractors equipped with two John Deere sweeps, the two outfits bucking hay to the same stacker at the same time. One tractor was equipped with 6.00 x 16 pneumatic tires in front and 11.25 x 24 pneumatic tires in the rear. Two wheel weights were used on each rear wheel. The other tractor was equipped with steel wheels and skid rings in front and steel wheels, each with one row of 5-in spade lugs, in the rear. It was our aim to have each tractor move the same amount of hay, but due to the personal element in drivers this cannot be exactly accomplished. It was our judgment that the steel-wheeled tractor moved more hay than the one with pneumatic tires. This was due to the drivers. Both moved all the stacker was able to handle most of the time, and occasionally more than it would handle. No change in wheel equipment was made for this test, but the fuel consumption was corrected for the difference in the two tractors, the characteristics of which were known at this time. The rubber-tired tractor used 92.05 per cent as many pounds of fuel per hour as the steel-wheeled tractor. It tore up the meadow much less where it approached the stacker. Both tractors traveled in high gear.

## Tractors Travel at Higher Speed with Rubber

Test No. 12, plowing barley stubble, was secured with two John Deere general-purpose tractors, and two John Deere two-bottom plows. One tractor was equipped with 6.00 x 16 pneumatic tires in front and 11.25 x 24 pneumatic tires with lug chains in the rear. The other tractor used the conventional steel equipment: steel wheels with skid rings in front, and steel wheels with two rows of 5-in spade lugs for each on the rear. Both types of wheel equipment were used on each tractor for this data. The tractors when equipped with pneumatic tires and chains traveled in high gear, but both were compelled to travel in intermediate gear when equipped with steel wheels and lugs. The rubber-tired tractors used 91.05 per cent as many pounds of fuel per acre as the steel-wheeled tractors and covered 119 per cent as many acres per hour.

Two weights were used on each drivewheel when equipped with rubber. Lugged chains that fit on one make of tractor tires, spacing all lugs equally, will have one unequal space when put on another make of tire. The tractor is rough riding when equipped with lugged chains.

When plowing in sandy soil, a rubber-tired tractor hav-




FIGS. 10, 11, 12, AND 13 THE RELATIONSHIP OF SPEED IN MILES PER HOUR TO DRAWBAR PULL IN POUNDS FOR FIVE TIRE INFLATION PRESSURES

ing no chains keeps the plow running at more nearly a uniform depth than a tractor equipped with steel wheels and spade lugs. The steel wheel with lugs running in a furrow in sandy soil digs up the bottom of the furrow considerably. The furrow wheel of the plow and consequently the plow is lowered by this action. Consequently as a steel-wheeled tractor strikes a sandy spot where its going is hardest, it automatically aggravates the situation by sinking the plow deeper. We plowed for about 10 h with these lugged chains and could see no appreciable wear on them, and none on the tires other than a very slight scuffing on one side of each tire. We were not sure this was due to the chains. The chains were unusually tight and crept but little.

Test No. 13, cultivation of corn third time over, was secured with a John Deere general-purpose tractor first equipped with steel wheels; skid rings in front and 5-in spade lugs in the rear, and then with 6.00 x 16 pneumatic tires in front and 11.25 x 24 pneumatic tires in the rear. When equipped with rubber tires, it could travel in high gear and did so throughout half the test, but it was our judgment that this tractor was overloaded when in high gear and that it would have been better judgment in this instance to have traveled in intermediate gear with both types of wheel equipment. This is one instance in our data where rubber tires used more fuel than steel wheels. They used 106.53 per cent as many pounds of fuel per acre and covered 101.55 per cent as many acres per hour. When equipped with steel wheels, it was compelled to travel in intermediate gear.

Test No. 14, mowing prairie hay, was secured with two John Deere general-purpose tractors and mowers on a wild hay meadow that was unusually rough. Where mowing is usually done in high gear, we considered it good judgment to mow this in intermediate gear. We also took time to back into each corner, thus making a clean job. This procedure cuts down the acreage considerably and increases the fuel consumption. No change in wheel equipment was made for this test. The fuel consumption was corrected to account for the difference in the tractors, their characteristics in this respect being known at the time of this test. The rubber-tired tractor used 89.7 per cent as many pounds of fuel per acre and covered 88.32 per cent as many acres per hour as the steel-equipped tractor. Each steel drive-wheel had one row of twenty-four 5-in spade lugs.

Test No. 15, the cultivation of corn the second time over, was secured with two John Deere general-purpose tractors and two three-row cultivators. One tractor was equipped with steel wheels and skid rings in front and steel wheels with 5-in spade lugs behind. The other tractor had steel wheels and skid rings in front and 11.25 x 24 pneumatic tires behind. It had been our intention to use the one tractor with rubber in front as well as in the rear, but with 15 lb pressure we could not steer it sufficiently well to keep it on the ridges. Our attempts to use the rubber tires in front took a considerable amount of time and used up quite a portion of the ground we had available for the test. Sending to town for steel wheels and skid rings to replace the rubber tires in front and then making the change took more time, and, instead of getting started with

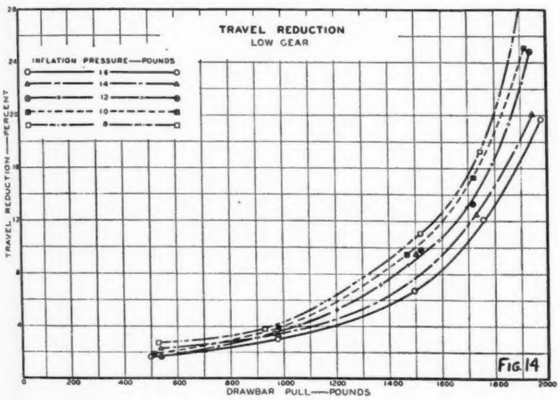
the test in the morning, it was 4.00 p.m. when all was running well. A three-hour run finished the field. We did not know the characteristics of these two tractors with respect to fuel consumption, so have only used the acres per hour. The rubber-tired tractor covered 102.21 per cent as many acres per hour as did the steel-wheeled tractor. The rubber-tired tractor ran in high gear. The steel-wheeled tractor ran in intermediate gear.

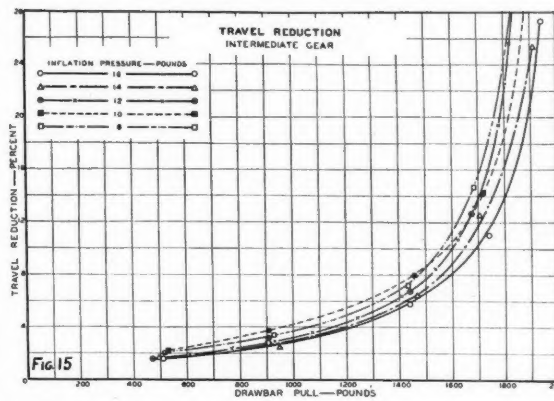
Test No. 16, plowing wheat stubble was made with one John Deere Model D tractor and a three-bottom Oliver plow. Two lands of equal areas, each 11.66 acres, were laid out; one was plowed, using steel wheels and six-inch John Deere lugs on the rear and steel wheels with skid rings in front. The other land was plowed, using 12.75 x 28 pneumatic tires on the rear and 7.50 x 18 pneumatic tires in front. The tractor when equipped with rubber used 91 per cent as many pounds of fuel per acre, and covered 90.96 per cent as many acres per hour as it did when equipped with steel wheels. A dense growth of grass and weeds covered the field. High gear was used throughout this test. The plowing depth was 6 in.

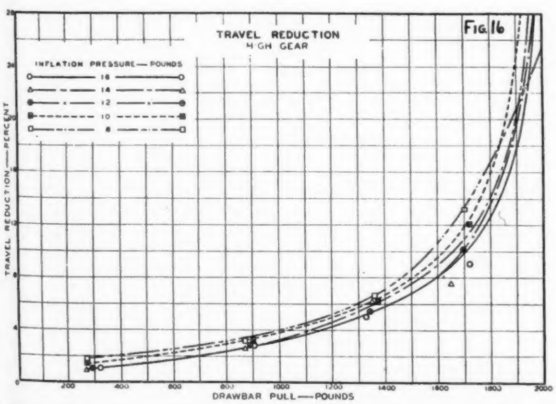
Test No. 17, plowing wheat stubble was made with one John Deere Model D tractor and a three-bottom John Deere plow. The usual procedure was followed laying out two lands of equal areas, one to be plowed using rubber-wheel equipment and the other using steel-wheel equipment. The wheel equipment corresponded to that described in test No. 16. The magneto gave some trouble during this test; not enough to interrupt the test, yet noticeable to the driver. For this reason, tests No. 16 and No. 17 are reported separately instead of together as had been planned. The tractor when equipped with rubber used 97.71 per cent as many pounds of fuel per acre and covered 93.02 per cent as many acres per hour as the tractor did when equipped with steel wheels. High gear was used in this test and the plowing depth was 6 in.

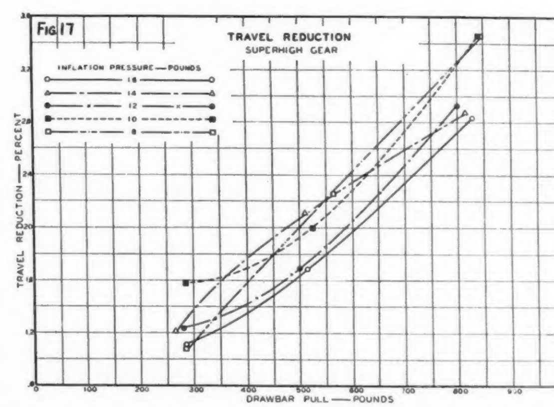
Test No. 18, plowing sweet clover, was made with the same John Deere Model D tractor and the same wheel equipment as described in test No. 16. A similar test had been planned and was begun with the tractor used in test No. 17, but serious magneto trouble caused it to be discarded. The owner of the tractor used in this test had cooperated on several tests during the summer and had concluded that a separate carburetor adjustment should be made with each type of wheel equipment, the same to be the most economical. The idea was carried out in this test. The tractor, when equipped with rubber, used 84.71 per cent as many pounds of fuel per acre and covered 85.97 per cent as many acres per hour. High gear was used in this test. The depth of plowing was 6 in.

Test No. 19, plowing alfalfa sod, was made with one Allis-Chalmers Model U tractor and an Allis-Chalmers three-bottom plow. The tractor in covering one-half the area laid out was equipped with 5-in spade lugs and steel wheels in the rear, and steel wheels with skid rings in front; and for the other half of the area was equipped with 11.25 x 24 pneumatic tires behind and 6.00 x 16 pneumatic tires in front. The entire test with both wheel equipments was made in intermediate gear. The tractor while equipped with rubber tires used 87.27 per cent as many pounds of

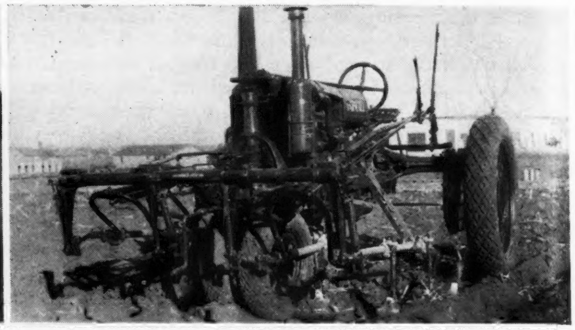



FIGS. 14, 15, 16, AND 17 THE RELATIONSHIP OF TRAVEL REDUCTION IN PER CENT TO DRAWBAR PULL IN POUNDS FOR FIVE TIRE INFLATION PRESSURES



fuel per acre and covered 87.4 per cent as many acres per hour as when equipped with steel wheels and spade lugs. The pneumatic tires slipped enough to stall the tractor one or more times on nearly every round. Four inches was the depth of the plowing. When plowing with steel wheel equipment, it was necessary once each round to shift to low gear, and the wheels slipped considerably at such times, but the steel wheels gave less trouble in the tough spots than the rubber tires.

Test No. 20, plowing alfalfa sod, was made with one Allis-Chalmers Model U tractor and a three-bottom 14-in Allis-Chalmers plow. The test was carried out as in test No. 19, except that the tractor when equipped with rubber was run in high gear. The pneumatic tires slipped enough in this test to stall the tractor one or more times each round, and the plows had to be raised some, making a depth less than four inches to get through these spots. The tractor when equipped with pneumatic tires used 101 per cent as many pounds of fuel per acre and covered 113.6 per cent as many acres per hour as when equipped with steel wheels and lugs.

Test No. 21, plowing wheat stubble, was made with two Farmall tractors and two two-bottom 14-in plows. Four lands were laid out, having the following areas: 9.36, 9.36, 8.71, and 8.27 acres. Each tractor covered two of these areas, one while equipped with steel wheels and 5-in spade lugs, and one while equipped with 9.00 x 36 pneumatic tires in the rear and 6.00 x 16 pneumatic tires in front. The land was almost level and was plowed 6 in deep. The tractors while equipped with rubber used 83.3 per cent as many pounds of fuel per acre and covered 108.22 per cent as many acres per hour as when equipped with steel wheels. Intermediate gear was used at all times.

Test No. 22, drilling wheat was made with a Case CC tractor and a 10 ft Moline press drill. The field was level and had previously been plowed, disked, and harrowed. The tractor was run in intermediate gear with open-type steel wheels and 3¼-in lugs, and in high gear with 9.00 x 36 pneumatic tires. When equipped with rubber, it used 74.82 per cent as many pounds of fuel per acre and covered

TABLE I

CORN PICKER QUANTITATIVE DATA

(While comparing steel wheels and pneumatic tires on tractors, October 20 and 21, 1933)

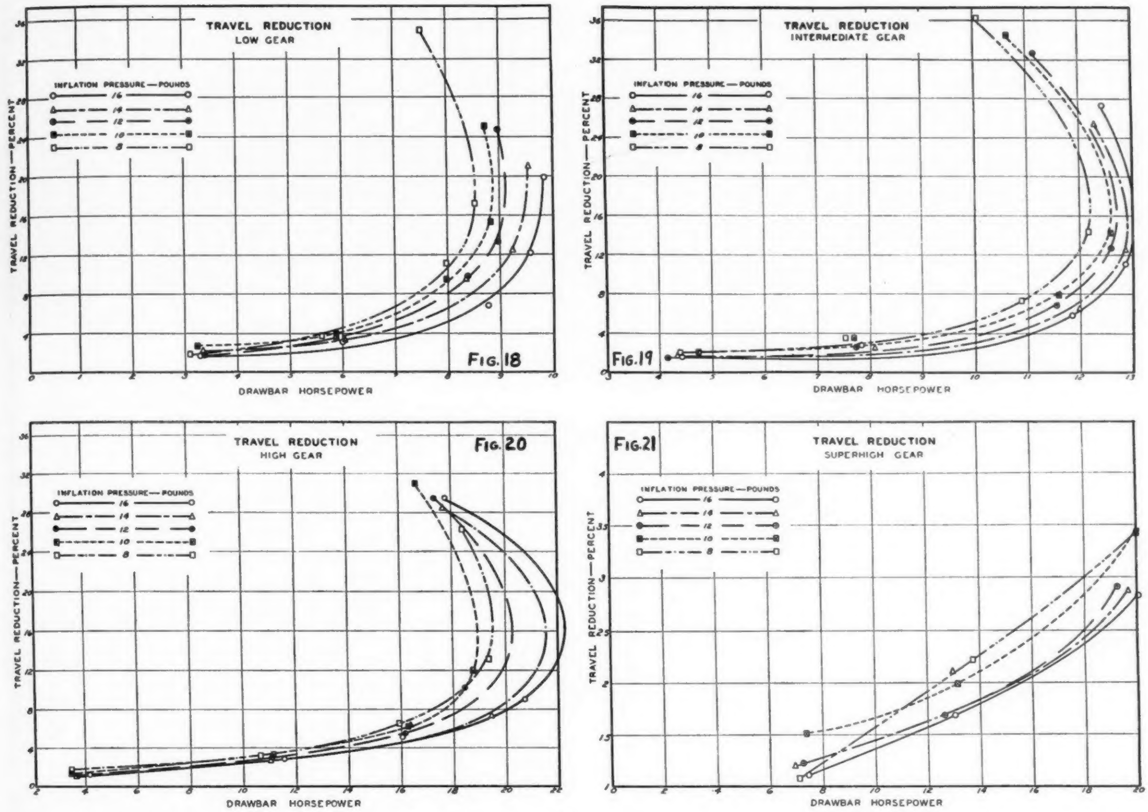
Equipment ........ I.H.C. corn pickers mounted on Farmalls
Weather condition........ Cloudy and cool, wind from south
Type of corn........ St. Charles White
Field condition........ Dry
Condition of stalks........ Tough, standing well

| Tractor no. | Test no. | Total no. rows | Length of rows—ft | Wheel equipment | Gear | Ave. no. ears per row | Ave. no. ears missed per row | Per cent missed |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 14 | 1764 | Pneumatic tires | Int. | 738.6 | 26 | 3.52 |
| 1 | 3 | 8 | 1764 | Steel wheels | Int. | 712.0 | 30.5 | 4.28 |
| 2 | 2 | 16 | 1764 | Steel wheels | Low | 752.0 | 23.5 | 3.12 |
| 2 | 4 | 8 | 1764 | Pneumatic tires | Int. | 666.0 | 30.5 | 4.58 |

CORN PICKER QUALITATIVE DATA

(Quantity used for each test was one bushel basket full of ears)

| Tractor no. | Test no. | Gear | Wheel equipment | Ears having following number of husks | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Above |
| 1 | 1 | Int. | Pneumatic tires | 24 | 6 | 3 | 7 | 4 | 0 | 1 | 0 | 0 | 0 | 2 | 11 |
| | | | Per cent........ | 43.37 | 10.34 | 5.17 | 12.07 | 6.90 | | 1.72 | | | | 3.44 | 18.97 |
| 1 | 3 | Int. | Steel wheels | 30 | 1 | 7 | 5 | 6 | 1 | 8 | 1 | 3 | 0 | 0 | 7 |
| | | | Per cent........ | 43.47 | 1.45 | 10.14 | 7.24 | 8.69 | 1.45 | 11.59 | 1.45 | 4.35 | | | 10.14 |
| 2 | 2 | Low | Steel wheels | 33 | 2 | 3 | 4 | 3 | 2 | 2 | 1 | 1 | 0 | 0 | 10 |
| | | | Per cent........ | 54.09 | 3.27 | 4.91 | 6.56 | 4.91 | 3.27 | 3.27 | 1.64 | 1.64 | | | 16.4 |
| 2 | 4 | Int. | Pneumatic tires | 25 | 2 | 6 | 1 | 3 | 5 | 5 | 1 | 3 | 1 | 0 | 6 |
| | | | Per cent........ | 43.10 | 3.45 | 10.34 | 1.72 | 5.17 | 8.62 | 8.62 | 1.72 | 5.17 | 1.72 | | 10.34 |




FIGS. 18, 19, 20, AND 21 THE RELATIONSHIP OF TRAVEL REDUCTION IN PER CENT TO DRAWBAR HORSEPOWER FOR FIVE TIRE INFLATION PRESSURES

136.3 per cent as many acres per hour as when equipped with steel. Steel wheels with skid rings were used in front throughout the test.

Test No. 23, picking corn, was made with a Farmall tractor and a two-row I.H.C. picker mounted on the tractor. The tractor was driven in intermediate gear first when equipped with steel wheels and 5-in spade lugs, and again when equipped with 11.25 x 24 pneumatic tires behind and 6.00 x 16 pneumatic tires in front. A careful check was made on the percentage of corn left in the field and also on the quality of the husking done. This can be seen in Table I. While equipped with pneumatic tires the tractor used 89.2 per cent as many pounds of fuel per acre and covered 89 per cent as many acres per hour as when equipped with steel wheels and lugs.

Test No. 24, picking corn, was made with a Farmall tractor and a two-row corn picker mounted on the tractor. This tractor was run in low gear with steel wheels and spade lugs, and in intermediate gear with pneumatic tires. The wheel equipment was similar to that in test No. 23. While equipped with pneumatic tires, 66.3 per cent as many pounds of fuel per acre were used, and 132.6 per cent as many acres per hour were covered as when equipped with steel wheels. For quality of husking, see Table I.

As part of the corn picking tests No. 23 and No. 24, data were taken on the quantitative and qualitative character of the work being done by the pickers. It was assumed that different speeds of operation might be reflected in the character of the work done. Five men in addition to those required to haul the corn away from the machines and the tractor drivers, were kept very busy for two days gathering these data. Every ear in 46 rows, each 1764 ft long, was counted before the rows had been touched by the machines. Every ear left on those same rows was counted after the corn had been picked by the machine. Bushel basket samples were taken as the tests progressed and the character of the husking being done recorded. Tabulation of these data can be seen in Table I.

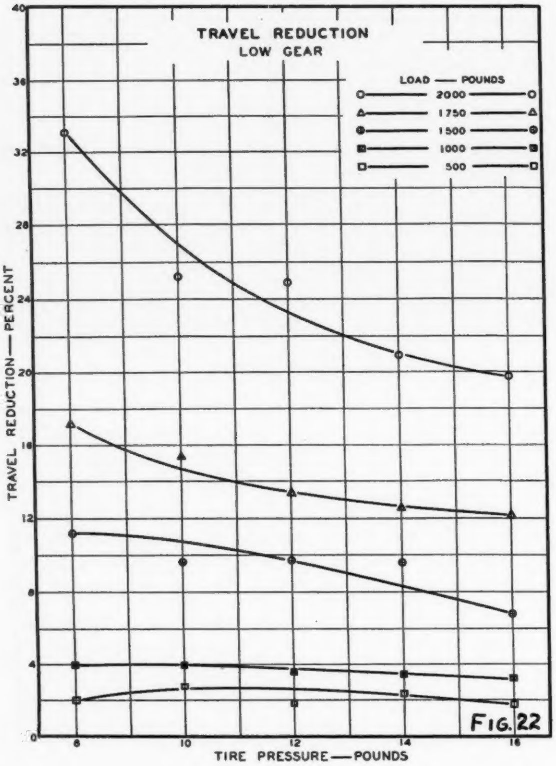
From the table it is evident that the percentage of ears missed did not depend upon the wheel equipment of the tractors, and, while the percentage was less for the tractor driven in low gear, the difference is not very significant. Likewise a close study of the quality of the husking reveals no startling evidence either for or against one type of wheel equipment or for low-gear driving.

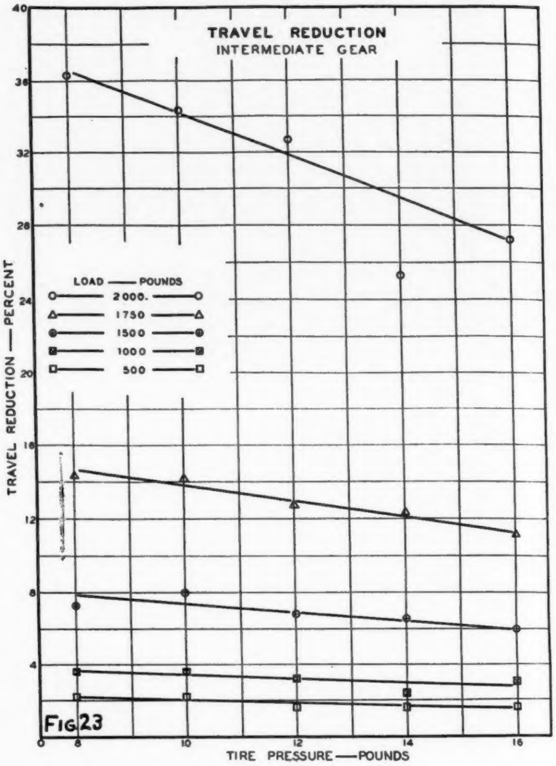
From our operations we make the following general conclusions:

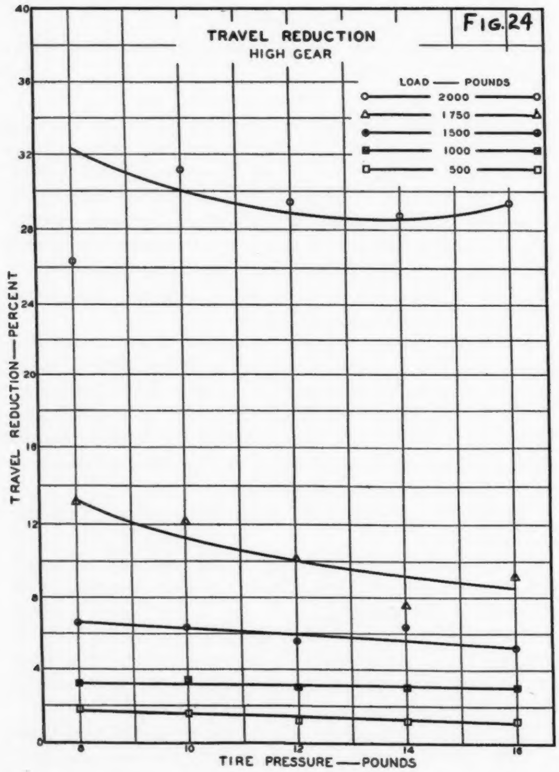
1 A rubber-tired tractor is harder to hold on listed corn ridges when cultivating than a tractor equipped with steel wheels and spade lugs.

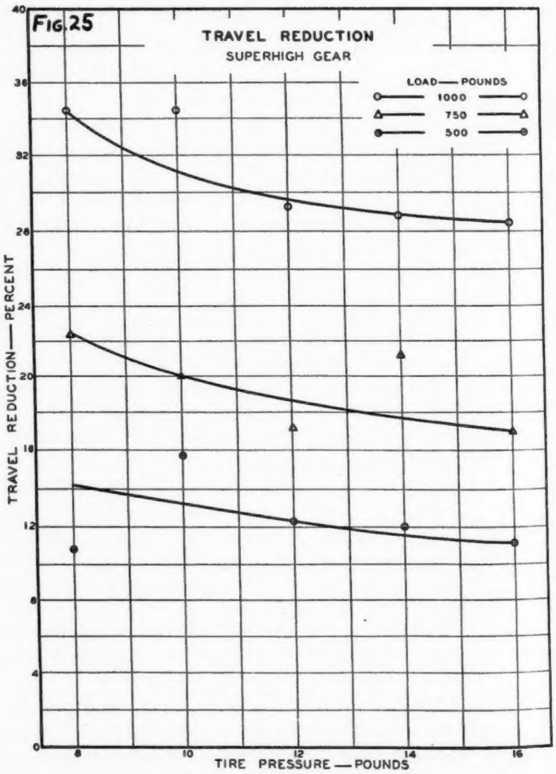
2 There was little difference this year in the ease of handling or of riding qualities between tractors equipped with rubber tires and those equipped with steel wheels when cultivating corn, except when on the ridges.

3 The riding qualities of a tractor equipped with rubber tires are very much better than those of one equipped with steel wheels and lugs when going to and from fields and when traveling on the road.




FIGS. 22, 23, 24, AND 25 THE RELATIONSHIP OF TRAVEL REDUCTION IN PER CENT TO TIRE INFLATION PRESSURE


4 The rubber-tired tractor is considerably better all round for haying operations than the tractor equipped with steel wheels and lugs. It does not punch hay into the ground. It does not tear up the ground when approaching the stacker with a sweep. In general, the riding qualities of the rubber-tired tractor are much better on a meadow. However, on meadows that are very rough an oscillating, bouncing motion is given to the rubber-tired tractor that not only affects the driver but is reflected in a rough job of mowing, due to the up-and-down movement of the sickle bar.

5 Many farming operations on sandy soil can be done better with rubber-tired tractors than with tractors equipped with steel wheels. This statement is based on operations and observations, some of which did not lend themselves to recorded numerical data.

6 A very considerable saving in time and in fuel can be made on many operations by the use of rubber tires. We saw ample evidence that a tractor will take in high gear with rubber tires that which made a full load in intermediate gear with steel wheels and lugs.

7 Front tire pressures should not be as low as 15 lb; we found 26 lb very satisfactory.

8 It would seem that the design of tread on a front tire should be different from that on a rear tire to correspond with the difference in duty of the two.

9 We encountered field conditions with a combine following rains, also with a plow, where the rubber tires slipped. Steel wheels and spade lugs were more satisfactory in these conditions. A set of lug chains is fairly simple to install and makes it possible to work in such conditions when possible to work with other wheel equipment.

10 In the field operations we encountered, we had no punctures. These operations necessitated an unusual amount of driving in and out of farm yards where punctures might be expected. We did, however, notice an old, rusty 10d nail in one casing and removed it.

11 In applying rubber tires to tractors it is necessary in some cases to widen the tread (the distance from the center of one rear tire to the center of the other). This handicaps the rubber tires when making comparisons between them and steel wheels.

12 Within the limits of its tractive effort a pneumatic tire is more efficient in transmitting power than a steel wheel and spade lugs.

13 There are many instances where rubber tires would be a more nearly ideal installation on a tractor than the conventional steel wheels and lugs from the operator's standpoint, and from that of the immediate job at hand. The economics of such installations will necessitate individual decisions on the part of purchasers.

14 Pneumatic tires to be used to the best advantage should be on tractors having sufficient selective speeds and such loads as will make possible comparatively high rates of travel.

15 Brakes on tractors will need to be improved when rubber tires are used. This is made necessary not only by the increased road speeds but also by the tendency of a rubber-tired tractor to coast at the ends of rows after implements have been raised.

To throw some light on the question of what is the best inflation pressure to use for tractor tires, some tests were run on the Nebraska Tractor Testing Course. The results cannot be given a universal application because they were arrived at on a track which had been well packed by much driving on it, but which was covered with a considerable amount of fine, dry dust. Practically no change occurred in the track condition, due to weather while the tests were being run, and the data in that respect are unusually good.

The procedure involved the use of five different drawbar loads, five different inflation pressures, and four different gears. Four separate runs were made, each for 500 ft, and then averaged for each point plotted in this report. Taking this inflation pressure data required the work of three men continuously for two weeks, and the compilation and computations involved in getting it ready for presentation required fully as much more work. And yet it is only a beginning to a thorough study of the subject.

### TESTS ON NEBRASKA TRACTOR TESTING COURSE

Drawbar pulls were secured by means of a hydraulic dynamometer placed between the tractor and the load. A record of the drawbar pull was secured by means of a Burr recording instrument, using a roll of sensitized paper. The drawbar charts were planimetered, and, by means of calibration charts for the springs used on the indicator in the Burr recording instrument, the pull in pounds was accurately determined. Speed of travel was arrived at by taking with stop watches the exact time required to cover a course of 500 ft.

Travel reduction was determined by first getting the effective circumference of the tire for each inflation pressure. This was accomplished by counting the exact number of revolutions of the drivewheels required to cover a definite distance when the tractor was pulling no load. The number of revolutions made by the drivewheels in traveling 500 ft under load was secured. The difference between the distance the tractor would have gone under no load and the distance it did go under load is called travel reduction. The travel reduction divided by the distance the tractor would have gone under no load is called the per cent travel reduction.

Five sets of charts have been made showing the results derived from work on the tractor testing course. The first

set shows the effect of tire inflation pressures on fuel consumption for various drawbar loads. From a practical standpoint these data show that tire inflation pressures have very little effect on fuel consumption.

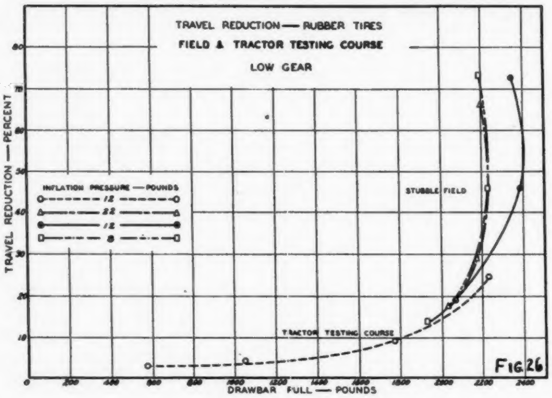
The second set of charts shows the effect of tire inflation pressures on speed in miles per hour for various drawbar loads. As would be expected, the speed decreases quite regularly as the pressure is decreased; also as the drawbar load increases.

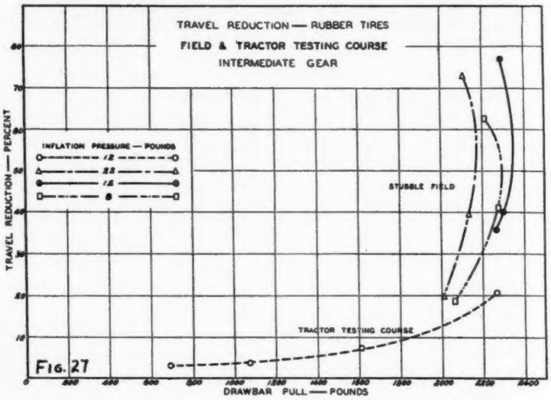
The third set of charts shows the effect of tire inflation pressures on travel reduction for various drawbar loads. The per cent of travel reduction increases with the decrease in tire inflation pressure, also with the increase in drawbar pull.

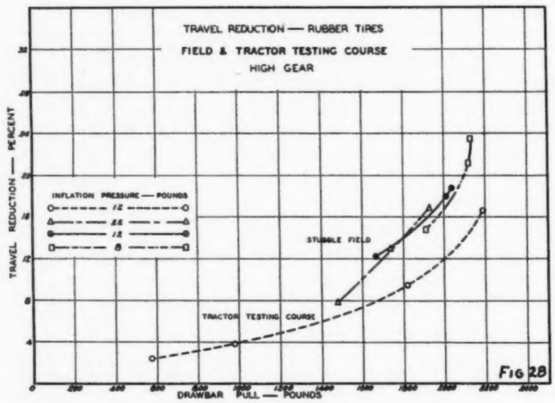
The fourth set of charts shows the effect of tire inflation pressure on travel reduction for changes in drawbar horsepower. For the conditions of this test, maximum drawbar horsepower decreased with a decrease in tire inflation pressure.

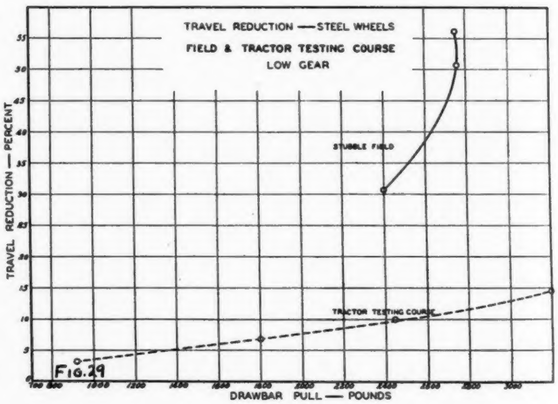
The fifth set of charts is a rearrangement of the data shown in the third set of charts; it shows the tendency of travel reduction to increase with a decrease in tire pressure.

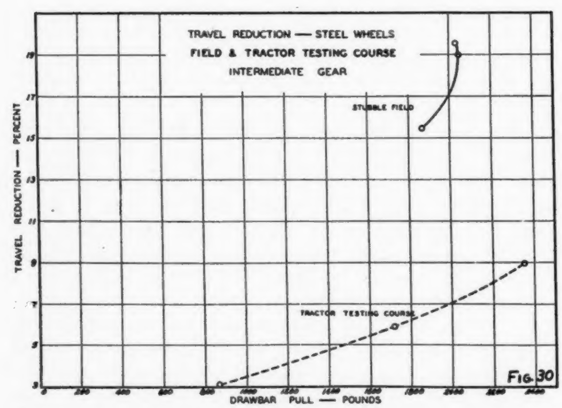
The question has been raised: Can maximum drawbar

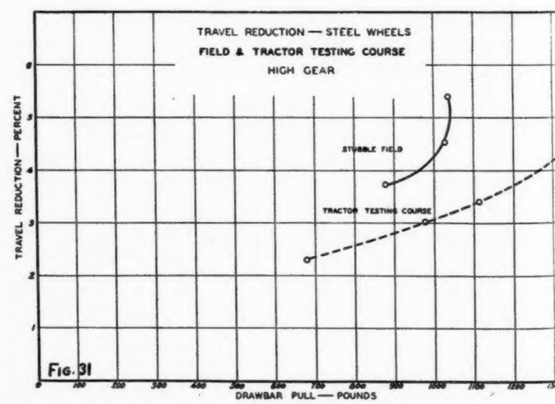



FIGS. 26, 27, 28, 29, 30, AND 31 A COMPARISON OF THE MAXIMUM DRAWBAR PULLS MADE BY THE SAME TRACTOR ON THE NEBRASKA TRACTOR TESTING COURSE AND IN A STUBBLE FIELD

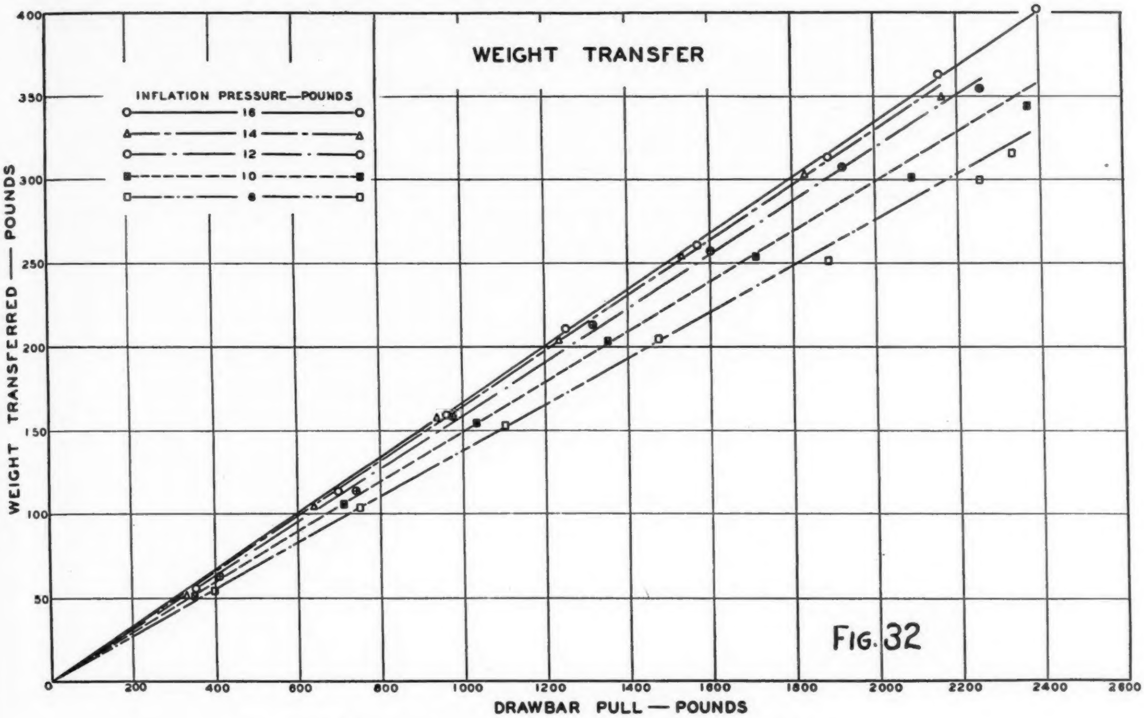
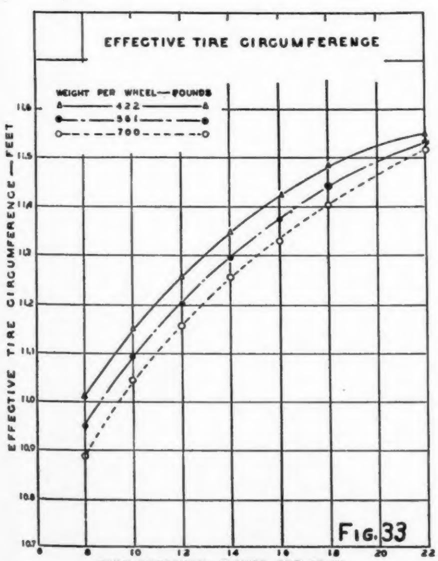
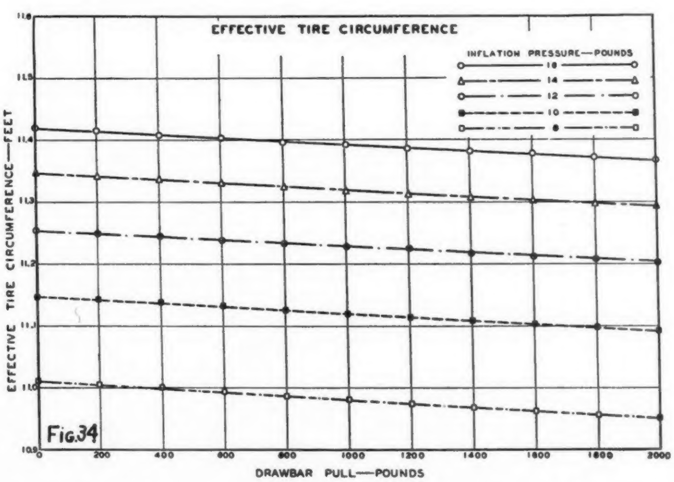



FIG. 32 WEIGHT TRANSFER AS AFFECTED BY DRAWBAR PULL

pull data taken on the Nebraska Tractor Testing Course be considered as representative of field conditions? To throw some light on this question, a stubble field was found which was practically level, had a considerable aftergrowth following the wheat harvest, and was being pastured lightly by a few cows and horses. Some maximum drawbar tests were run in it. Three different inflation pressures were used, and three different loads were pulled in the vicinity of maximum with each of these inflation pressures and in each of three gears. Courses were laid out for these tests so that the tractor and testing equipment never followed the same track twice. These data are shown graphically in Figs. 26, 27, 28, 29, 30, and 31. For purposes of comparison curves were plotted on the same figures with data secured on the tractor testing course with the same tractor earlier in the year. From these figures it can readily be seen that a change in footing from the tractor testing course to a stubble field made very little difference in the maximum drawbar pull with pneumatic tires, but did make a considerable difference for steel wheels and lugs.




FIGS. 33 AND 34 EFFECTIVE TIRE CIRCUMFERENCE AS AFFECTED BY TIRE PRESSURE DRAWBAR PULL

Another question in the minds of those interested in the application of pneumatic tires to tractors is: What part of what we have chosen to call travel reduction is due to slippage and what part is due to a transfer of weight from the front end of the tractor to the rear? It is generally understood that there is a transfer of weight from the front end of a tractor to the rear, proportional to the drawbar pull, and that this transferred weight decreases the effective diameter of pneumatic tires. With this question in mind, a brief study of the same has been made. It has not been covered in an exhaustive manner. The crankshaft of a tractor was locked, the gear shift placed in low, a windlass chair hoist and hydraulic dynamometer placed between the drawbar and a post, a platform scale placed under the front end of the tractor, all being located on a concrete floor. Care was taken to see that the dynamometer was at the same height as the drawbar. A 175-lb weight was placed on the tractor seat. The gas tank was three-fourths full, and the radiator was full. A series of increasing drawbar pulls was applied to the tractor until the wheels slipped, readings being taken on the weight transferred and the drawbar pull. Results of this work are plotted in Fig. 32.

## Data Taken with Different Sizes of Wheel Weights

A second set of data was secured by attaching three different sizes of weight—422, 561, and 700 lb—to each rear wheel of the same tractor, and then with each determining the effective circumference of the wheels on the tractor testing course, as previously described. These data are shown graphically in Fig. 33.

From the weight transfer curves, Fig. 32, the weights transferred for different drawbar pulls were found. These weights were added to the static weight of the rear end of the tractor and the total divided by two to give the weight on each rear tire. These figures were taken to the effective circumference graph, Fig. 33, and by interpolation the effective circumferences were determined. Results of these calculations are shown graphically in Fig. 34.

The effect of weight transfer upon travel reduction for two inflation pressures is shown by Table II.

Table II covers a series of drawbar pulls largely within the practical range for the tractor being used in securing the data. It is seen that in no case calculated did the weight transfer account for more than one-half of one per cent of the travel reduction.

It can be shown by computations for this same tractor, by the use of Figs. 32, 33, and 34, that, if the entire weight on the front wheels of this tractor were transferred to the rear wheels, it could not account for more than 2.5 per cent travel reduction.

TABLE II. THE EFFECT OF WEIGHT TRANSFER UPON TRAVEL REDUCTION

(16-lb tire pressure—low gear)

| Drawbar pull, lb | Revolutions of drivers in 500 ft | Circumference of tire, in inches: No load | Circumference of tire, in inches: Corrected for weight transfer | Per cent travel reduction based on: No load circum. | Per cent travel reduction based on: Corrected circum. | Difference, per cent |
|---|---|---|---|---|---|---|
| 1977.5 | 54.850 | 11.421 | 11.368 | 20.18 | 19.81 | 0.37 |
| 1754.2 | 50.080 | 11.421 | 11.374 | 12.58 | 12.22 | 0.36 |
| 1494.2 | 47.225 | 11.421 | 11.380 | 7.30 | 6.96 | 0.34 |
| 975.0 | 45.440 | 11.421 | 11.393 | 3.66 | 3.42 | 0.24 |
| 498.8 | 44.875 | 11.421 | 11.406 | 2.44 | 2.31 | 0.13 |
| (8 lb tire pressure—low gear) | | | | | | |
| 1918.2 | 70.040 | 11.021 | 10.952 | 35.23 | 34.82 | 0.41 |
| 1742.2 | 54.975 | 11.021 | 10.958 | 17.48 | 17.00 | 0.48 |
| 1518.0 | 51.225 | 11.021 | 10.964 | 11.43 | 10.97 | 0.46 |
| 925.0 | 47.290 | 11.021 | 10.982 | 4.06 | 3.72 | 0.34 |
| 505.0 | 46.375 | 11.021 | 10.994 | 2.17 | 1.93 | 0.24 |

From tire deflection data taken in the laboratory on another tire of the same size but of different make, it was shown that by adding weight equal to that of the front end of this tractor to the rear tires, the per cent of travel reduction caused would be 3.98 per cent.

Where these two percentages are not in very close agreement, they do show that weight transfer can account for only a small per cent of the travel reduction experienced with pneumatic tires.

In addition to the field operations reported with data, many other operations have been carried on with tractors equipped with pneumatic tires for which no tabulated data were taken, such as disking plowed ground with a Case Model L tractor and a 14-ft disk, listing several acres with an Allis-Chalmers Model U tractor and a Chase two-row lister, studying the action of a Farmall tractor on freshly made lister ridges, and driving an Allis-Chalmers Model U tractor with trailer loaded with two three-bottom plows on the highway from Omaha to Lincoln, approximately 60 m, in less than four hours.

Some tabulated drawbar data on dirt road surfaces have been taken; also data on tire deflections and contact areas which are not being reported at this time.

Most of the special investigations have been touched only superficially but the primary objective, namely that of using pneumatic tires on a wide variety of farm operations and securing accurate information on the same, has certainly been rounded out as completely as the most optimistic could have hoped for in one season's work.


# A SUMMARY

## Pneumatic Rubber Tires on Farm Equipment

By Walter B. Jones[1]

THE TECHNICAL PAPERS in these pages bring together for detailed study and correlation results of experience and experimentation with rubber tires in a number of states during 1933. All but one of these papers are the work of agricultural engineers in colleges of agriculture, or of their accompanying agricultural experiment stations.

As will appear to the intensive reader, almost any attempt at brief general statements regarding the use of soft rubber tires in farm work, especially on the driving wheels of tractors, is challenged by exceptions. The summary following does not ignore, though it must omit, many of these superficially contradictory findings.

### Low Rolling Resistance

The outstanding characteristics of the low-pressure pneumatic tire is its low rolling resistance. Under most conditions of farm usage this is substantially less than that of the alternative steel wheel equipment, the power or draft reduction ranging up to about 60 per cent and approaching 70 per cent in some of the striking comparisons. It seems worthy of mention, in evaluating these studies and in planning others, that the values of rolling resistance seem to vary according to the method of measurement, or rather with the conditions of operation under which measurement is attempted. In at least some soil conditions a wheel advancing by virtue of its own rotation, though free from any external resistance such as drawbar pull, seems to encounter more rolling resistance than when it is towed or pulled by external force.

If this is true of a wheel setting up a horizontal force only sufficient to overcome its own rolling resistance, there is reason to believe that the effect increases as drawbar pull is developed, and that tests with free-rolling wheels are no true measure of rolling resistance of tractive wheels.

Although major attention has been given to the pneumatic tire as a tractor drive member, its easy-rolling properties apparently reach a higher value in free-wheeling applications, such as the front wheels of tractors and as the wheels of power-driven combines, corn-pickers, etc.

On the guiding wheels of tractors the low-pressure tire is reported by most observers as making the tractor easier to handle, subject to less slippage, and so permitting shorter turns, especially when turning under load. However, cases were noted in which short turns were more laborious with low inflation pressures than with moderately higher pressures. In running on ridges to cultivate listed corn, accurate steering was more difficult with rubber tires.

This was ascribed, at least in part, to the rear tires being mounted at a different and less favorable tread width than the steel, displacing the tire from the middle of the ridge. Tread alteration also has disturbed the relation between tractor and plow, handicapping the performance of the rubber tires.

As a traction member, the rubber tire has, with few exceptions, appeared to be more efficient but less effective than the lugged steel wheel. Within its limitations the rubber tire usually delivers more of the developed engine power to the drawbar, due mainly to saving of power by lower loss in rolling resistance. In some conditions, notably in sand, there may be materially less slippage with rubber, as well as lower rolling resistance.

### Limitations of Tractive Effort

The limitations of the rubber tire as a traction member are due to the fact that its tractive adhesion is mainly frictional, as compared with the lugged wheel whose engagement with the soil is comparable to that of a spur gear with a rack. On comparatively dry soils of most types the performance of a rubber tire is comparable to that of a rubber belt driving a pulley. There is a small percentage of slip or creep which increases steadily though slowly up to a certain point at which total slippage occurs. This point of maximum draft is much more sharply defined, and usually occurs at materially lower values, than is the case with lugged wheels.

In such conditions, tractive pull available is a function of the force between the frictional surfaces, that is, of weight on the tires. In consequence, tractors which have been developed in the direction of light weight are equipped with wheel weights to increase the maximum drawbar pull. Due to the low rolling resistance this is not, at least on level ground, objectionable.

This combination of limited pull with a rolling resistance which is low, and which seems not to increase sharply with speed, enables the rubber-tired tractor to show striking increases in capacity and economy at light and medium pulls at rather high speeds. The economy is apparent at any speed provided the engine is operated at a favorable load factor.

When the moisture in or on the soil exceeds a certain rather critical value, the performance of a rubber driving tire is comparable to that of a rubber belt in a shower. Its tractive effort falls off so sharply and so far as to render it ineffective for practical work. The precise percentage of moisture at which this limitation asserts itself varies with many contributing influences, and in combination with them may be said to constitute the problem for the engineer to solve in determining the application of rubber tires, in the present state of the art, for tractive uses.

In practical farm work there is nothing comparable to the operation of a vehicle tire on a wet concrete pavement. But if we assume that the frictional characteristics of a concrete road are due to the grains of sand presented at the surface, we have a seeming analogy. The more a soil partakes of the nature of sand in its presentation to the tractor tire, the more tolerant of moisture it seems to be.

On the other hand, it appears that the presence of organic or other colloidal material in the soil reduces the amount of moisture which can be tolerated before slippage becomes a limiting factor. So we find that certain types of fine clay, some humus-filled loams, and soils containing or covered with succulent green growth, are ill-adapted to rubber traction in the presence of considerable amounts of moisture. Unfortunately it is just these soils which are retentive of moisture, while the green growth supplies

[1]Assoc. Mem. A.S.A.E.

moisture of its own. Plowing alfalfa sod offers an example of succulent matter both in the soil and on the surface, coupled with a heavy draft requirement. Up to the slippage point this job is done efficiently with rubber traction, but in many cases this limit is passed and serious difficulty follows.

Regions of limited rainfall, and particularly where the heavy operations are performed in the dry season, yield reports of favorable experience with rubber traction, coupled with personal enthusiasm by operators and observers. The dust nuisance, which with lugged wheels often obscures vision besides its discomfort to man and detriment to machine, with rubber is largely abated.

The more humid regions in many cases also have soils of such type and content as to aggravate the traction limiting effect of moisture. An example to be singled out is Wisconsin, which might be dubbed the battleground of rubber vs. steel. By mere coincidence its tractor industry includes both the outstanding pioneer in the promotion of rubber-tired tractors and a conspicuous conservative, exceeding cautious in endorsing rubber.

Besides plenty of rainfall and considerable soil sensitive to moisture, it also happens that rainy periods are likely to come during critical periods of farm work. This, with a rather short season and a prevailing system of farming in which delayed operations and time-wastage are serious matters, has made the tractor motive in Wisconsin largely one of getting work done on schedule in spite of weather. Hence the limitations of the rubber tire loom so large that it is distinctly on trial in that state, whatever may happen elsewhere.

### Types of Operation

The preponderance of experience is that rubber tires are far superior to lugged wheels in all hayfield work, in nearly every minor as well as major consideration. Pretty much the same is true of every type of small-grain harvesting. Not only on the tractor but under the combine, the rubber tire has reduced the power requirement, speeded up operation, and in at least some cases has mitigated limiting conditions. In small grain stubble the efficiency and adaptability of the rubber-tired tractor extend to plowing or other tillage work.

In freshly tilled soil, the variables are so many and so wide that generalization is difficult. Reported results show seeming conflicts. It appears that most such operations are performed satisfactorily without running into the limitations of rubber, and with rather scattered efficiencies for which a weighted average probably would be better than for steel. Rubber has shown high efficiency in seeding small grain. In distinctly dry soils the advantage seems definitely with rubber, though the differences in efficiency and capacity are not so great as in stubble or similarly firm footing, where the spading action of steel lugs consumes considerable power charged up to rolling resistance.

Rubber tires have proven satisfactory in corn cultivation, but without striking advantages in capacity or economy, nor with a monopoly of minor advantages. Harvesting corn with the picker-husker has given the rubber-tired tractor its most widely publicised debacle. Combinations of highly tilled soils, deep and soft, or covered with slime when thawing starts after a freeze, perhaps complicated with snow, ice, or sleet, are about as unfavorable to rubber traction as can be imagined. Ill-adapted as rubber traction may seem for developing drawbar pull by the tractor, rubber tires found one of their first applications under the picker-husker for reducing its rolling resistance, and so its drawbar requirement. For the drawn-type corn harvester, and also for the tractor with mounted picker-husker, the rubber tire is at least promising.

The addition of tire chains, notably of the lug type, is technically successful in overcoming, to at least a large degree, the limitations of rubber traction. Limited observation suggests that a large part of the easy-rolling feature is retained. In some cases the rubber tire with chains is self-cleaning while lugged wheels are not. Probably in most conditions where rubber tires call for chains, the steel wheel would be economically superior. The time required and the attendant circumstances of attaching chains are against them, both economically and psychologically. Their riding qualities are often bad, and thus far they are not a happy solution of the rubber tire's most serious problem.

Other than first cost and interest thereon, rubber tires in typical farm tractor service present no great cost problem. Apparently no tractor tire has yet worn out, and observed wear is so slight as to promise life running into the years. Deterioration during idle periods is as yet an unanswered question. Trouble from cuts and punctures has been of very rare occurrence, and the cost and success of repairs to these tires therefore remains largely a matter of opinion. Occasional valve stem troubles suggest room for their better protection and for improved tire anchorage.

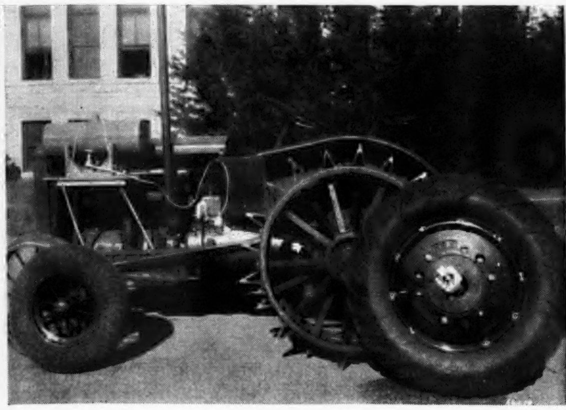
For haulage or transport on paved or any reasonably good road surface the rubber tractor tire may be considered a foregone success at any speed up to eight or ten times the field speeds considered usual. The tractor, however, calls for improvements in braking, steering, and front axle geometry. Indeed, even for field use we have as yet no tractors really designed to run on rubber tires. All applications thus far are substantially makeshifts of steel-wheel jobs.

Barring resistance to the investment cost, the psychology of the user seems to be overwhelming in favor of rubber tires for tractors. Dust mitigation has been mentioned, and to this should be added a large measure of comfort for many conditions of operation. Under some conditions, however, bouncing becomes not merely a matter of discomfort, but of actual personal hazard.

### CONCLUSIONS

Embraced among the accompanying papers, though not here reviewed, is the use of low-pressure pneumatic tires on haulage units such as farm wagons or trailers. Such applications seem to have sufficient advantages and annual use to promise economic justification for rather general adoption throughout the United States. The same may be said as to the ground wheels of field implements or machines with which rolling resistance is a dominating factor in successful operation, or where the product of annual usage with efficiency gain justifies the fixed charges on investment. Standardized, interchangeable wheels used in succession on sundry units might extend the usefulness of rubber tires in this class of service.

Where ground adhesion for traction is required, no such generalization can be made in the present state of knowledge and development. It seems likely that there may be one zone of adaptability for rubber tires and another for lugged steel wheels, as has long been true of the adaptations of chilled and steel plows. To the extent that soil conditions influence the adaptability of rubber tires, there may even be a degree of coincidence in the field of the rubber tire and the chilled plow. It seems certain, however, that the field for rubber tractor tires is large enough to warrant continued and intensive engineering study, and to justify vigorous, though discriminating, commercial exploitation.



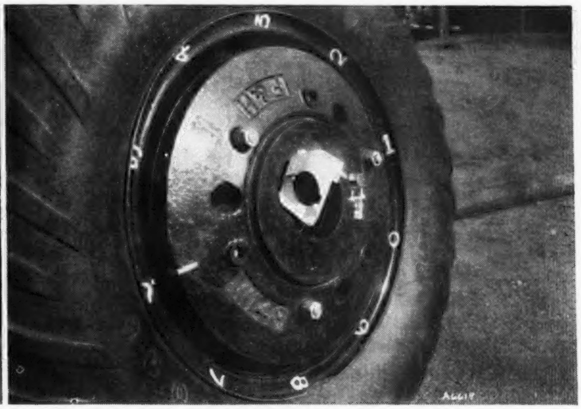


FIG. 1 (LEFT) THE INTERCHANGEABLE TRACTOR WHEEL EQUIPMENT USED IN THE KANSAS TESTS. FIG. 2 (RIGHT) THE VEEDER REVOLUTION COUNTER MOUNTED IN POSITION

# Comparative Field Tests in Kansas of Rubber Tires and Steel Wheels[1]

By Frank J. Zink[2], E. L. Barger[3], June Roberts[4], and T. E. Martin[5]

DURING THE SPRING and summer of 1933, a series of comparative tests was made to obtain information on the relative merits of pneumatic rubber tractor tires and regular steel wheel equipment. Thirteen separate tests were conducted in three fields of different characteristics and soil type in the vicinity of Manhattan, Kansas. Plowing and disking operations in the course of soil preparation for various spring-planted crops were prescribed by the farmer operators of the land on which the tests were run. Tests should be made on many other field operations and on soils of different types and conditions to establish a comparison of the two types of tractor wheel equipment under consideration. It is the purpose of this paper to report results of tests that have been made to date at Kansas State College.

In each test equal areas that were as nearly as possible comparable in all characteristics were covered with each type of traction equipment. Fig. 1 shows the interchangeable wheel equipment. For the most part, the comparisons were made on the same day. In no case were the comparative tests interrupted by extreme weather changes that would materially change the field conditions. Data were taken on implement draft, area covered, time, fuel consumption, drivewheel slippage, and rolling resistance.

All draft readings were taken with an Iowa dynamometer which was calibrated before the work started to insure its accuracy. In order to speed up the taking of draft readings, the spool device for winding the thread with which the dynamometer is equipped was replaced with a quadruple-geared fishing tackle reel, attaching it to the dynamometer case. A sufficient number of dynamometer readings were taken to eliminate as far as possible any errors caused by large variable conditions of soil, soil type, and contour.

Slippage was measured in each test by first running the tractor idle over the length of the test field and counting the wheel revolutions. Then throughout each test a record was taken of the wheel revolutions with the tractor pulling the test load. The difference was considered slippage. The revolutions of the drivewheels were counted by means of two Veeder continuous counters suspended at the drive axle by their ratchet arms. By this means one forward revolution of the drivewheel advanced the counter one digit. A counter balance attached to the counter served to keep the device always suspended with the indicating window upward. Fig. 2 shows the Veeder counter in mounted position.

The term "rolling resistance" is taken to mean the power consumed in moving the tractor over the ground at the test speed. It was measured by pulling the test tractor, with the dynamometer in the hitch, with another tractor to measure the power required. Rolling resistance data were taken at several different speeds in each test, and speed versus horsepower curves were constructed. From these curves the rolling resistances at the test speeds were read.

A detachable auxiliary tank was used to furnish fuel for the test runs. This tank was connected into the regular fuel line with a three-way valve controlled from the driver's seat. The regular fuel tank was used for warming-up runs and turning at ends. A scale measuring accurately to one one-hundredth of a pound was used to weigh the fuel consumed. Fig. 1 shows the auxiliary fuel tank.

Test fields for plowing were laid out with two furrows across the ends at right angles to the line of travel. The furrows were about five yards apart and far enough from the ends to allow ample room for turning. The outer furrow was used as a stopping point to take wheel revolution

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers held at The Stevens, Chicago, December 1933. Contribution No. 67 of the department of agricultural engineering, Kansas State College.

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counter readings. The second or inner furrow served as a marker on which to switch the fuel valve, on or off, from the auxiliary tank and a point to start or stop the timer's watch. The area covered was calculated, using the distance between the inner furrow marks as the length, and the average width across the land worked as the width.

Each test field used in disking was laid out with one furrow at right angles to the line of travel. At this point the wheel counters were read, the fuel valve was switched, and the timer was started as the tractor started from the furrow position. These were changed and stopped, respectively, as the tractor reached the cross furrow at the opposite end of the field. In the disking tests the areas were calculated from the length of run and width of the implement. The equipment was handled as in ordinary field practice.

Two tractors were used in the test work. All plowing tests and the disking tests in Field B were made with an Allis-Chalmers Model U tractor. The regular steel wheel equipment consisted of 42-in diameter by $11\frac{1}{2}$-in face rear wheels and 28-in diameter by 6-in face front wheels. Twenty spade lugs 5 in high and with 3.5-in face were used on each rear wheel. Rubber tire equipment for this tractor consisted of French & Hecht drop-center rim wheels and Firestone tires, 6.50 x 16 in front and 11.25 x 24 in rear. An air pressure of 12 lb per square inch was carried in the rear tires and 15 lb per square inch in the front tires. Three cast-iron wheel weights totaling about 400 lb were used on each rear wheel. A John Deere general-purpose, narrow-tread tractor was used in the disking tests in field C. The regular steel wheels were $42\frac{3}{4}$-in diameter by 10-in face in rear and 24-in diameter by 6-in face in front. Twenty-four John Deere spade lugs 4 in high and with 3-in face were used on each rear wheel. This tractor also used French & Hecht drop-center rim wheels for rubber tire equipment. Goodyear tires were used, 6.50 x 16-in in front and both 11.24 x 24 and 13.50 x 24-in tires on the rear wheels. Also on this tractor cast-iron wheel weights totaling about 400 lb were attached to each rear wheel.

A John Deere No. 4 two-bottom 16-in plow with general-purpose bottoms was used in all plowing tests.

Disking tests were made with McCormick-Deering 7-ft tandem disk harrows.

*Plowing—Field A.* The soil of Field A is classified as a Laurel fine sandy loam. It is river bottom land used for truck farming and had grown a crop of sweet potatoes the previous season. It had been double-disked about six weeks before the plowing tests. No rain had fallen between disking and plowing, and the surface soil down about four inches was very loose and dry. The farmer's instructions were to plow it between 8 and 10 in deep. The tractor used was the Allis-Chalmers Model U with wheel equipment as described above.

It was possible to pull the two-bottom, 16-in plow at the desired depth with steel wheels in second gear but not in third gear. With rubber equipment it was possible to go to the higher or third gear. Table I shows the results of plowing tests in Field A. It required 81.7 and 84.5 per cent as much time per unit area, in the two tests, with the rubber tires as with steel wheels. The fuel economy per unit area was 9.9 and 12.8 per cent in the two tests in favor of the rubber. Rolling resistance of the tractor at the working speeds on this soil was found to be 3.9 hp and 3.95 hp with the rubber-tired wheels and 10.5 hp and 10.6 hp with the steel wheels, respectively. Considerable slippage could be expected due to the character and condition of the soil. The regular steel wheels and lugs gave slightly less slippage than the rubber tires. In the first test it was 11.27 per cent for the steel wheels compared with 13.65 per cent for the rubber tires. There was greater slippage of the land wheel than of the furrow wheel of the tractor when equipped with tires. In one check the rubber-equipped land wheel was found to be slipping as much as three times the rate of the furrow wheel slip. This became more serious as the plowing depth was increased because of the increased angularity and shifting of weight to the lower wheel. In cases of this kind it may be advisable to shift more of the wheel weights to the land wheel to effect a balance. This was not tried in this test.

*Plowing—Field B.* Field B is also river-bottom land but of a Laurel silt loam classification. It had been in alfalfa for five years and pastured with hogs the previous year. The ground was firm, free from trash on top, and full of alfalfa roots. It appeared in every respect to be ideal for steel wheel operation. The lugs penetrated well but did not stir the ground appreciably. The field was plowed 6 to 7 in deep at the request of the farm manager. At 6 in deep the plow could be handled in third gear with both the steel wheels and rubber tires. As the depth was increased to nearly 7 in, it was possible to pull the plow only in second gear with either type of traction equipment. Separate tests were run at the two depths and conditions, the results of which appear in Table I as Test 1 and Test 2.

A higher average speed in both tests resulted with the steel wheel equipment. It required 14.3 per cent more time in Test 1 and 7.3 per cent more time in test 2 to cover a given area with the rubber tires than with steel wheels. The fuel saving with the rubber equipment was 13.2 per cent when running the tractor in third gear in Test 1 and 4.2 per cent when in second gear in Test 2. In the second gear

TABLE I. PLOWING TESTS

| | Field A 1st test | | Field A 2nd test | | Field B 1st test | | Field B 2nd test | |
|---|---|---|---|---|---|---|---|---|
| | Steel | Rubber | Steel | Rubber | Steel | Rubber | Steel | Rubber |
| Depth, average inches | 10.10 | 9.63 | 8.77 | 8.55 | 6.08 | 6.06 | 6.56 | 6.85 |
| Area plowed, acres | 0.71 | 0.69 | 0.79 | 0.74 | 0.30 | 0.29 | 0.37 | 0.35 |
| Approximate implement input, hp | 14.00 | 17.00 | 14.00 | 17.00 | 20.00 | 20.00 | 18.00 | 18.00 |
| Speed, gear | 2nd | 3rd | 2nd | 3rd | 3rd | 3rd | 2nd | 2nd |
| Speed, mph | 3.71 | 4.67 | 3.74 | 4.72 | 4.76 | 4.44 | 3.56 | 3.47 |
| Time of test, min | 38.03 | 30.17 | 37.75 | 29.90 | 11.08 | 11.85 | 17.78 | 18.20 |
| Time per acre, min | 53.50 | 43.65 | 47.81 | 40.40 | 36.30 | 41.50 | 48.30 | 51.90 |
| Time per acre, per cent | 100.00 | 81.70 | 100.00 | 84.50 | 100.00 | 114.30 | 100.00 | 107.30 |
| Fuel used, lb | 15.71 | 13.80 | 14.77 | 12.08 | 6.25 | 5.07 | 7.46 | 6.81 |
| Fuel per acre, lb | 22.20 | 20.00 | 18.70 | 16.30 | 20.50 | 17.80 | 20.25 | 19.40 |
| Fuel per acre, per cent | 100.00 | 90.10 | 100.00 | 87.20 | 100.00 | 86.80 | 100.00 | 95.80 |
| Rolling resistance, hp | 10.50 | 3.90 | 10.60 | 3.95 | 10.50 | 3.30 | 7.50 | 2.40 |
| Rolling resistance, per cent | 100.00 | 37.60 | 100.00 | 37.80 | 100.00 | 31.40 | 100.00 | 32.00 |
| Slippage, per cent | 11.27 | 13.65 | | | 7.21 | 8.83 | 6.40 | 9.23 |

TABLE II. DISKING TESTS

| | Field B 1st test | | Field B 2nd test | | Field C 1st test 13.50 tires | | Field C 2nd test 11.25 tires | | Field C 3rd test 11.25 tires | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Steel | Rubber | Steel | Rubber | Steel | Rubber | Steel | Rubber | Steel | Rubber |
| Area disked, acres | 1.37 | 1.37 | 3.43 | 3.43 | 1.19 | 1.19 | 1.19 | 1.19 | 1.19 | 1.19 |
| Approximate implement input, hp | 13.00 | 12.00 | 12.00 | 12.00 | 8.00 | 13.00 | 9.50 | 12.00 | 10.00 | 10.00 |
| Speed, gear | 2nd | 2nd | 2nd | 2nd | 2nd | 3rd | 2nd | 3rd | 2nd | 2nd |
| Speed, mph | 3.46 | 3.19 | 3.22 | 3.20 | 2.44 | 4.02 | 2.81 | 3.59 | 3.08 | 3.03 |
| Time of test, min | 28.03 | 30.38 | 75.40 | 75.80 | 33.83 | 24.96 | 35.69 | 27.98 | 27.25 | 27.66 |
| Time per acre, min | 20.65 | 22.10 | 22.00 | 22.10 | 28.50 | 20.90 | 30.00 | 23.50 | 23.00 | 23.20 |
| Time per acre, per cent | 100.00 | 106.80 | 100.00 | 100.50 | 100.00 | 73.40 | 100.00 | 78.50 | 100.00 | 101.00 |
| Fuel used, lb | 10.95 | 10.32 | 33.64 | 27.67 | 10.41 | 7.94 | 10.63 | 8.69 | 10.20 | 8.97 |
| Fuel per acre, lb | 8.00 | 7.54 | 9.81 | 8.06 | 8.76 | 6.76 | 8.94 | 7.30 | 8.54 | 7.52 |
| Fuel per acre, per cent | 100.00 | 94.40 | 100.00 | 82.20 | 100.00 | 77.30 | 100.00 | 81.30 | 100.00 | 88.10 |
| Rolling resistance, hp | 10.60 | 5.80 | 9.45 | 5.80 | 5.20 | 4.00 | | | | |
| Rolling resistance, per cent | 100.00 | 54.60 | 100.00 | 61.50 | 100.00 | 77.00 | | | | |
| Slippage, per cent | 18.40 | 18.20 | 24.22 | 18.02 | 13.95 | 7.14 | 17.81 | 8.03 | 13.05 | 11.70 |

speed the wheel slippage was greatest with the rubber, 9.23 per cent compared with 6.40 per cent for the steel wheels. In the third gear test the steel also had the advantage, 7.21 per cent slippage compared with 8.83 per cent for the rubber equipment. Rolling resistance on this ground was 10.5 hp for the steel and 3.3 hp for the rubber at the plowing speeds in Test 1, and 7.5 hp for the steel and 2.4 hp for the rubber in Test 2.

*Disking—Field B.* A part of Field B described above had been plowed in the fall of 1932 and had laid over the winter in an unworked condition. Tests with a 7-ft tandem disk harrow were made on this field, the results appearing in Table II. The tractor used was the Allis-Chalmers with wheel equipment as described. With neither type of wheel equipment was it possible to run in third gear. The slippage with the steel wheels was 18.4 per cent compared with 18.2 per cent for the rubber, in the first test. The second test was run several days later with the soil drying to some extent during the interval between the tests. In the second test the steel wheels slipped 24.22 per cent compared with 18.02 for the rubber. It required 6.8 per cent more time for the rubber equipment on the first test and slightly more time for the rubber on the second test. The fuel saving amounted to 5.6 and 17.2 per cent, respectively, in the two tests for the rubber equipment.

*Disking—Field C.* Field C was upland with an Oswego silt loam classification. In Tests 1 and 2, sorghum stubble was disked. In Test 3 disking was done on fall-plowed alfalfa ground. The John Deere general-purpose standard tread tractor with equipment as listed above was used. Both 11.25 x 24 and 13.50 x 24 Goodyear tires were used in this test. Table II gives the comparative figures on these tests.

In disking on the cane stubble, with both the 11.25 and the 13.50 tires, it was possible to pull the disk harrow in one gear higher speed than was possible with steel wheels. This resulted in a time saving of 26.6 per cent for the 13.50 tires and 21.5 per cent for the 11.25 tires over the steel equipment. The 13.50 tires gave a fuel saving per unit area of 22.7 per cent, while the 11.25 tires gave 18.7 per cent saving over the steel wheels. In these tests wheel slippage was less with the rubber tires, being 7.14 per cent for the 13.50 tires against 13.95 per cent for the steel wheels, and 8.03 per cent for the 11.25 tires against 17.81 per cent for the steel wheels. Rolling resistance at the test speed with the 13.50 tires was but 4.0 hp as compared with 5.2 hp for the steel wheels, or a reduction in rolling resistance of 23.0 per cent.

In disking on the alfalfa ground there was a saving of 11.9 per cent in fuel, but with 1.0 per cent greater time for the rubber equipment. In this test it was only possible to handle the load with both equipments in the second gear. Increased tractor rolling resistance was probably responsible for this result. Good year 11.25 x 24 tires and the John Deere tractor were used in this test.

Table III gives a summary of all tests. Each type of test is assembled in a group; also a final summary is shown of all tests. In comparative tests of this nature the advantage of either type of equipment depends much upon the load and the gear speeds. In cases where there is considerable difference between gear ratios, and it is not quite possible to go into a higher gear with steel wheels, it means falling back to a lower gear. In such cases it is frequently possible to handle the load in the higher gear with rubber tires, thereby resulting in a time and fuel saving in favor of the rubber-tire equipment. It should be pointed out, however, that this is not always possible in farming practice. The farmer cannot sacrifice depth of tillage or thoroughness of work to take advantage of the larger savings made possible by changing the load to suit the conditions.

The effect of speed on performance is shown in Table IV. In the first column is summarized the results of tests in which it was necessary to run the tractor in second gear

TABLE III. SUMMARY OF TESTS

| | Plowing (4 tests) | | Disking (5 tests) | | All Tests (9 tests) | |
|---|---|---|---|---|---|---|
| | Steel | Rubber | Steel | Rubber | Steel | Rubber |
| Time per acre, min | 46.47 | 44.36 | 24.79 | 22.36 | 34.42 | 32.13 |
| Time per acre, per cent | 100.00 | 95.96 | 100.00 | 92.36 | 100.00 | 94.37 |
| Fuel per acre, lb | 20.41 | 18.37 | 8.81 | 7.43 | 13.85 | 12.29 |
| Fuel per acre, per cent | 100.00 | 89.97 | 100.00 | 84.66 | 100.00 | 87.02 |
| Rolling resistance, per cent | 100.00 | 34.70 | 100.00 | 62.17* | 100.00 | 47.41† |
| Slippage, per cent | 8.84‡ | 9.88‡ | 17.45 | 12.66 | 13.65 | 11.40 |
| Slippage, per cent (steel 100) | 100.00 | 111.00 | 100.00 | 72.50 | 100.00 | 83.40 |

*Average of five tests †Average of seven tests ‡Average of three tests

with both steel and rubber-wheel equipment. From this it can be seen that the advantages of the rubber tires are influenced by gear and speed. There was a loss in time of 4.27 per cent, but in other respects the advantages were in favor of the rubber-tired tractors. The rolling resistance was 53.9 per cent less, which resulted in a saving of 9.88 per cent fuel.

In the test where it was possible to run in third gear with both types of equipment, considerably more time was required, but the other advantages of the rubber tires are somewhat greater than in the tests where the second gear was used. In this test the rate of travel was greatest with the steel wheels, and it required 14.3 per cent less time per unit area with steel wheels. Wheel slippage was greater with rubber tires by 22.3 per cent, rolling resistance was reduced by 68.6 per cent, and the fuel saving was 13.2 per cent.

The greatest contrast between the equipment compared occurred in cases where load and ground conditions permitted running the tractor in a higher speed with rubber tires than with steel wheels. Because of the greater speed with rubber tires, the rolling resistance is some greater than where both were run in the same gear, but the time saving reaches 21.5 per cent, the fuel saving 16.0 per cent, and slippage is only 63.8 per cent of that resulting with steel wheels.

Fig. 3 shows the relation between the rolling resistance of the Allis-Chalmers Model U with the two types of wheel equipment over a speed range of from 0.7 to 6.9 mph (miles per hour). These tests were run on sorghum stubble ground similar to those of Field C. The ground was dry, firm, and free from trash. The rolling resistance of the rubber-tired tractor ran from about 25 per cent at one mile per hour to about 45 per cent at 6 mph of that of the steel wheels.

The following brief conclusions may be drawn from the data taken and the observations made:

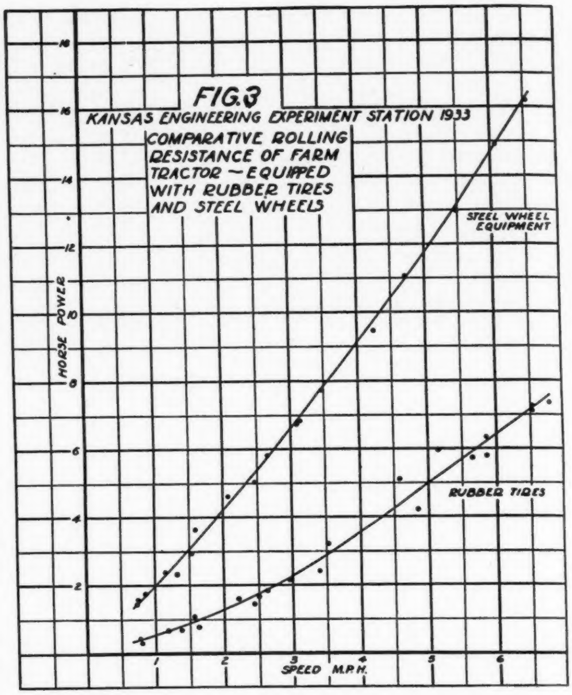
1 Rubber tires were more efficient at higher speeds.

2 Decreased rolling resistance was the largest single factor responsible for the increased efficiencies of the rubber tires. In all tests the average rolling resistance of rubber tires was but 47.41 per cent of that of regular steel wheels.

3 Slippage of the rubber tires was 16.6 per cent less than that of steel wheels.

4 It was observed that jarring and vibration when operating over hard or rough ground were eliminated with rubber tires.

5 Under most conditions the comfort of the operator was greatly increased by rubber tires.




6 Certain field conditions such as cross-travel on row-crop fields resulted in rebounding or bouncing with rubber tires that was more severe than with steel wheels. Certain load conditions in some cases near the full-load point also produced rhythmic rebounding with rubber equipment.

7 Relative efficiencies of rubber tires and steel wheels were greatly affected by tractor speeds, loads, and ground conditions. The greatest differences appeared when conditions are such that it was possible to handle the load at a higher speed with rubber tires than with steel wheels.

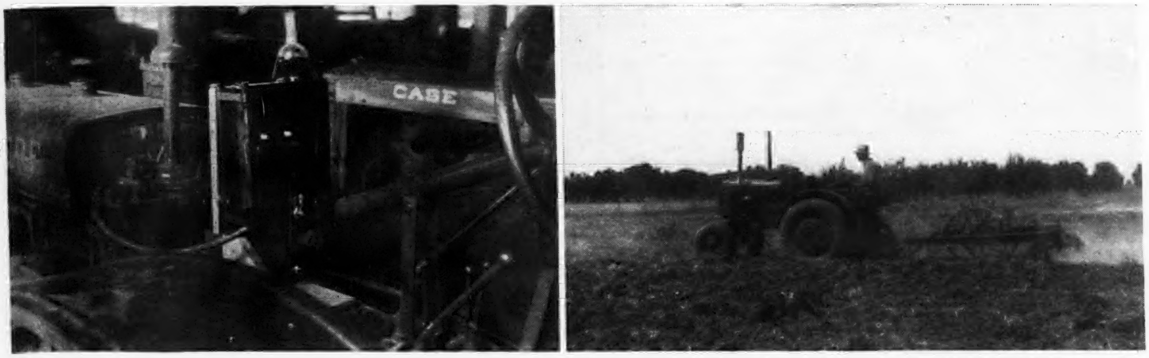
8 Fuel savings made possible by the use of rubber tires was appreciable and for the nine tests averaged 12.98 per cent. This saving was due largely to the decreased rolling resistance.

9 Rubber tires caused much less dust to be stirred up in dry fields. In some of the tests with steel wheels it was necessary to stop and let the dust clear away in order to see to turn at the ends, while with rubber tires this was not necessary.

TABLE IV. SUMMARY OF TESTS SHOWING EFFECT OF SPEED ON PERFORMANCE

| | Second Gear Tests Average (4 tests) | | Third Gear Tests (1 test) | | Both Gears Steel in 2nd gear Rubber in 3rd gear Average (4 tests) | |
|---|---|---|---|---|---|---|
| | Steel | Rubber | Steel | Rubber | Steel | Rubber |
| Speed, mph | 3.33 | 3.22 | 4.76 | 4.44 | 3.19 | 4.25 |
| Time per unit area, per cent | 100.00 | 104.27 | 100.00 | 114.30 | 100.00 | 79.50 |
| Fuel per unit area, per cent | 100.00 | 90.12 | 100.00 | 86.80 | 100.00 | 83.97 |
| Rolling resistance, per cent | 100.00 | 46.03* | 100.00 | 31.40 | 100.00 | 58.43 |
| Slippage, per cent | 15.52 | 14.33 | 7.21 | 8.83 | 12.72* | 8.13* |
| Slippage, per cent (steel 100) | 100.00 | 92.40 | 100.00† | 122.30† | 100.00 | 63.80* |

*Average of three tests †Plowing on alfalfa sod



(LEFT) DEVICE FOR MEASURING TRACTOR FUEL CONSUMPTION AT SHORT INTERVALS OF OPERATION. (RIGHT) RUBBER-TIRED TRACTOR PULLING CHISEL IN CALIFORNIA TESTS

# Tractive Performance of Pneumatic Tires and Steel Wheels[1]

By B. D. Moses[2] and K. R. Frost[3]

THE INTEREST in low-pressure rubber tires for farm tractors throughout the country and the many inquiries regarding their merits prompted the agricultural engineering division of the University of California, at Davis, to conduct a series of tests. According to investigations in the Midwest and East, these tires are adapted to general farm work; and they may soon be widely adopted. The purpose of the present tests was to determine performance, at least under one set of conditions, of rubber tires compared with steel wheels and lugs. This paper will contribute information on the underlying principles that govern the tractive performance of pneumatic rubber tires.

Field tests with a tractor equipped alternately with rubber tires and steel wheels, and pulling a tillage tool under the same conditions, will reveal the relative advantages and disadvantages. For sake of comparison, drawbar horsepower, wheel slippage, tractor speed, and engine fuel consumption were measured for different loads.

The soil in the fields where the tractor was operated was a light clay loam. Traction conditions at the time of the tests were very good, the soil being firm and dry to a depth of 12 to 14 in. Part of the field was just as it was left after the hay had been cut; the remainder had been disked to a depth of 5 or 6 in.

The tractor equipment used for the tests was a John Deere general-purpose tractor and a set of Firestone pneumatic tires, wheels, and weights. The tillage implements were a subsoil chisel and an offset disk harrow. In order to obtain a maximum horsepower by the use of a steady load, a second tractor was towed for a few tests.

The drawbar horsepower was measured with an Iowa dynamometer that records the pull on a paper tape for a distance of 50 ft. The area under the penciled curve represents the mechanical work and when timed gives a measure of speed and power.

Fuel was measured by a three-bowl burette, each bowl holding 112 cc. The upper bowl supplied the fuel till the tractor was under way; and as the fuel level passed a mark on the neck between the first and second bowls (sometimes the second and the third also), the time required was measured with a stop watch.

Before being taken into the field, the tractor was bolted to a Sprague dynamometer, and the carburetor was adjusted for smoothest engine performance at rated horsepower. This was not the most economical setting, but furnished a standard for occasional checking. The setting was not changed throughout the tests, since the tractor engine was quite consistent in performance.

A series of tests was run with steel wheels in one gear, and for one soil condition. Then rubber tires were substituted, and a duplicate series was run. This method when applied to all three gears and for both soil conditions served to minimize errors arising from delay.

The load was varied by changing the depth of the chisel teeth. This was done eight or ten times for each series of runs, starting with a light load and increasing it until the tractor was either stalled or wheel slippage was considered excessive. When steel wheels and lugs were used, the engine would stall if the tractor was overloaded, but with rubber tires the tire slippage controlled the maximum load.

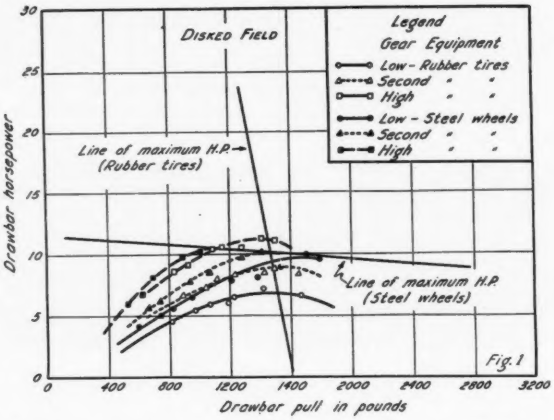
In order to determine the rolling resistance of each type of wheel, fuel consumption tests of the tractor were also run, both with rubber tires and steel wheels on disked and firm soil, with no tool attached. These runs were made in each gear, the fuel and speed being measured over a distance of 300 to 400 ft.

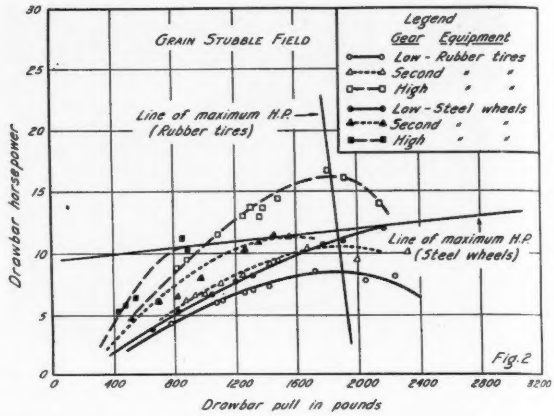
A comparison of the drawbar horsepower for various pulls is shown in Figs. 3 and 4 for the tractor operating in disked and stubble fields. If a straight line is drawn approximately through the maximum points on the two sets

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers at Chicago, December 1933.

[2]Associate professor of agricultural engineering and associate agricultural engineer in the experiment station, University of California. Mem. A.S.A.E.

[3]Associate in agricultural engineering, University of California. Jun. A.S.A.E.




of curves in each figure, it is practically horizontal in the case of the steel wheels and vertical in the case of the rubber tires. The vertical line for rubber tires indicates a constant limit of traction, beyond which the wheels slip. The horizontal line for steel wheels shows merely that the maximum power of the engine is the limiting factor. It is significant that the maximum drawbar horsepower obtained with rubber tires is both above and below the maximum obtained with steel wheels; in fact, it points to a definite criterion for the selection of tires in relation to speed and load.

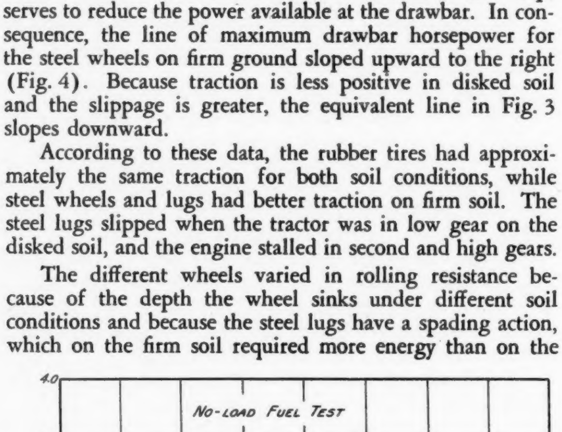
The slope of this line then becomes a measure of traction, starting from horizontal for positive traction and rotating clockwise until vertical for perfectly smooth wheels. The energy expended in moving the tractor at high speeds exceeds that at low and, when the wheels cannot slip, serves to reduce the power available at the drawbar. In consequence, the line of maximum drawbar horsepower for the steel wheels on firm ground sloped upward to the right (Fig. 4). Because traction is less positive in disked soil and the slippage is greater, the equivalent line in Fig. 3 slopes downward.

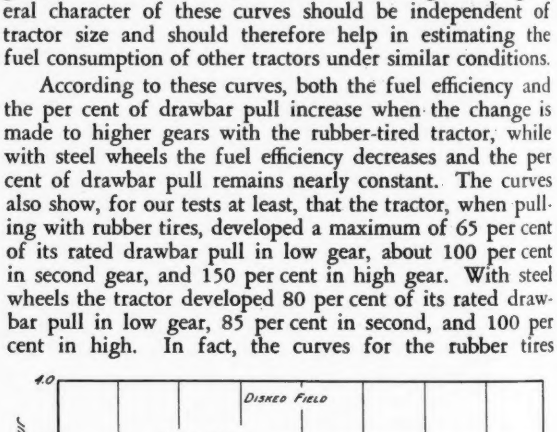
According to these data, the rubber tires had approximately the same traction for both soil conditions, while steel wheels and lugs had better traction on firm soil. The steel lugs slipped when the tractor was in low gear on the disked soil, and the engine stalled in second and high gears.

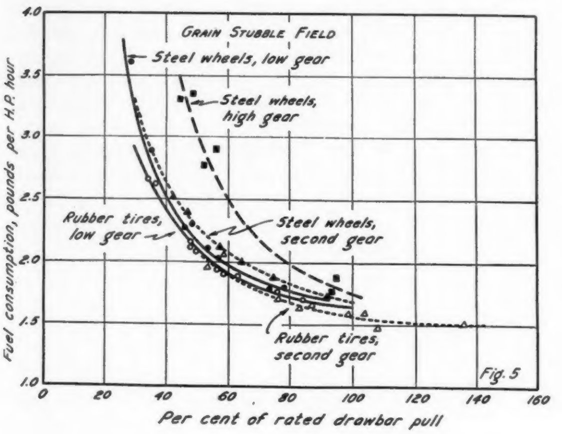
The different wheels varied in rolling resistance because of the depth the wheel sinks under different soil conditions and because the steel lugs have a spading action, which on the firm soil required more energy than on the disked soil, while the rubber tires required less. This point is illustrated in Fig. 5, where the fuel consumption per mile of travel is shown to be lower on disked than on firm soil with steel wheels, and higher for the rubber tires. In either case the rubber tire does not waste energy in cultivating the soil. With rubber tires on disked soil, the fuel required to move the tractor alone was from 8 to 19 per cent less than with steel wheels; on firm ground, from 28 to 35 per cent less.

The relation of fuel consumption per horsepower-hour to per cent of rated drawbar pull has been plotted in Figs. 1 and 2, as a generalized basis for comparison. This rated drawbar pull is based upon Nebraska Test 190, assuming that the ratio of maximum pull to that developed at rated speed is a constant. The values used were 2270 lb for low gear, 1702 lb for second, and 1009 lb for high. The general character of these curves should be independent of tractor size and should therefore help in estimating the fuel consumption of other tractors under similar conditions.

According to these curves, both the fuel efficiency and the per cent of drawbar pull increase when the change is made to higher gears with the rubber-tired tractor, while with steel wheels the fuel efficiency decreases and the per cent of drawbar pull remains nearly constant. The curves also show, for our tests at least, that the tractor, when pulling with rubber tires, developed a maximum of 65 per cent of its rated drawbar pull in low gear, about 100 per cent in second gear, and 150 per cent in high gear. With steel wheels the tractor developed 80 per cent of its rated drawbar pull in low gear, 85 per cent in second, and 100 per cent in high. In fact, the curves for the rubber tires






can practically be connected end to end, while those for steel wheels are somewhat parallel. The differences in fuel consumption and drawbar pull are caused by the traction characteristics of each type of wheel.

## SUMMARY

For the conditions of our tests:

1 The pneumatic rubber tire had a decided advantage over the steel wheel in fuel consumption at higher speeds.

2 A higher per cent of the rated drawbar pull can be developed in second and high gears with the rubber tires than with steel wheels.

3 Steel wheels with lugs showed a higher per cent of drawbar pull in low gear.

4 Slippage is the controlling factor limiting the load drawn with rubber tires, while the steel-wheeled tractor is limited by the power of the engine.

5 The maximum horsepower is increased when the gear changes are made to higher speeds with the rubber-tired tractor; it is decreased with steel wheels.

6 At any given per cent of rated drawbar pull, the rubber-tired tractor is more economical for each gear ratio on either firm or cultivated soil.

7 The fuel required to move the tractor without load is less with the rubber tires than with steel wheels and lugs. The rubber tires roll with less resistance on firm soil; the steel wheels, on cultivated soil.

# Field Test of Rubber-Tired Tractor Wheels[1]

By R. I. Shawl[2]

THE 9½-YEAR-OLD, general-purpose tractor used by the department of agricultural engineering, University of Illinois, was given a new lease on life last spring, when it was equipped with the new low-pressure rubber tires. The farmer who had run this tractor for the past six years, after plowing a few rounds at four miles an hour, said that it seemed like new life had been put into the tractor.

In January 1933 a set of 11.25 x 24 and 6 x 16 tires were put on this Farmall 20 tractor No. 691, which has been operated continuously at general farm work since June 1924. At the end of December 1933 the tractor has completed 9½ years of operation and 5928 hours of work.

The observations made on the use of rubber tires for tractors were taken from the 855 hours of general farm work which this tractor completed during 1933.

The two front tires as used on this tractor allowed shorter turning on soft ground and plowed ground without slipping, than could be accomplished with steel wheels. The tires are self-cleaning and do not ball up with grass and mud under wet conditions. This makes rubber tires especially desirable on the narrow front wheels of general-purpose tractors.

No trouble was encountered with punctures in the rear tires, but three punctures were experienced in the front tires from the sharp stubble left while moving weeds in a pasture. Air had to be added to the front tires several times during the past nine months of operation, but the rear tires required air only once in the left tire and twice in the right tire. The air was supplied by a few strokes from a hand tire pump to which had been attached an extra long air hose.

The weights were not removed from the wheels at any time because the ground was quite dry and no objectionable packing occurred. The farmer did not feel like spending the time removing and putting on the weights.

Very little rain fell during this season's work, and it was found necessary to use the chains only twice. Both of these times were during plowing when the ground was slippery on top.

The tractor was operated in high gear, or approximately four miles per hour, and had plenty of power to pull all the implements that the tractor had formerly pulled at three miles per hour with steel wheels. On one occasion the speed of the tractor had to be reduced while disking plowed ground, because the large clods caused the tractor to bounce so much that the operator could not stay on the seat.

In cultivating soybeans this wheel equipment worked very successfully pulling two eleven-foot rotary hoes covering 22 feet of ground. The soil was dry and loose, but the tires had ample traction to pull this load in high gear with practically no damage to the beans from the tires. Short turns were made with this load without difficulty. In 1932 the tractor equipped with steel wheels, pulling the same two hoes at three miles an hour, had so much wheel slippage and tore out so many of the young plants that one of the hoes had to be removed.

The fuel consumption per hour of operation of the tractor varied but little when both steel wheels and rubber tires were used, as can be seen from the following table:

| Fuel consumption (kerosene) | Gallons per hour |
|---|---|
| 8½ years of operation prior to 1933 covering 5073 hours of work with steel wheels | 1.46 |
| 1932 only for 730 hours of work with steel wheels | 1.60 |
| 1933 only, for 855 hours of work with rubber tires | 1.49 |
| 1930 was the lowest | 1.21 |
| 1927 was the highest | 1.65 |

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers, at Chicago, December 1933.

[2]Assistant professor of agricultural engineering, University of Illinois. Assoc. Mem. A.S.A.E.

The advantage of the increased working speed of the tractor due to the use of rubber tires is emphasized by the following figures taken from the records of this tractor.

This fall (1933) 227 acres of three-year old Lespedeza clover ground were plowed in 221 hours' time, or at the rate of 1.03 acres an hour, requiring 1.70 gallons of kerosene per acre. In the fall of 1930 this same tractor equipped with steel wheels plowed 205 acres of wheat stubble at the rate of 0.68 acre per hour and required 2.08 gallons of fuel per acre.

These figures show a gain of 0.35 acre plowed per hour for the rubber-tired wheels and a saving of 0.37 gallon of fuel per acre plowed, which is quite a significant saving in time and fuel. The ground which was plowed 7 inches deep, was dry and hard in both cases, and contained about an equal amount of root growth.

The tires show very little wear and apparently should last for several seasons more of use, if the winter storage is not too hard on them. The farmer on whose farm this tractor is being used is thoroughly "sold" on rubber tires for this size of tractor.

# Wisconsin Observations of Rubber Tire Performance

By F. W. Duffee[1]

EXPERIENCES of the agricultural engineering department of the University of Wisconsin during the past year with rubber-tire equipment for tractors were largely in the nature of observation of field performance rather than engineering tests.

The pneumatic rubber tires which we have are on a standard four-wheel type of tractor weighing complete, without the man on the seat, 3850 lb. To this we added two wheel weights to the furrow wheel, or about 300 lb, and three wheel weights to the land wheel, or about 450 lb. These weights are in addition to the weight of the tractor itself.

All the work which we did was done during the spring seedbed preparation and planting period, which during the past year was unusually wet. Our idea was first to determine as quickly as possible the limitations of the equipment, and we soon found that there are many field conditions under which the tire alone will not perform successfully. These consisted especially of wet ground conditions, whether on sod or on fallow land. We also found that the traction seemed to be comparatively low on rather loose fallow land unless the tires were equipped with chains.

After using the tractor on our own farms this spring, it was loaned to the city relief authorities to be used in plowing some thirty-five or forty acres of garden tracts throughout the suburbs of the city. One of our own men who was particularly capable used the tractor for this work. I will cite some of his experiences while plowing these tracts of land. On one occasion he had to be pulled out of a hole with one of the county's four-wheel-drive trucks, and at another time he and his assistant spent approximately four hours digging the tractor out when it mired down. He found that, when a tractor without chains runs into a soft spot and mires down, it is practically absolutely helpless, unless some kind of chain equipment can be attached to the wheels, whereas on a steel-wheel machine equipped with lugs it is usually possible to get the tractor to lift itself by the use of rails or posts.

During all our experiences last spring we were working practically between showers. However, it is the ability of the tractor to perform successfully under just exactly these conditions that the Wisconsin farmer finds his principal advantage in this equipment. Wisconsin ranks third or fourth of the states in the number of tractors on farms, and one of the principal and most important reasons for the use of tractors on these farms, which are as a whole relatively small, is their ability to go out and get jobs done quickly and on time. Our season, of course, is comparatively short and the work day is very materially shortened by virtue of the time required for doing chores in connection with the dairy business, which is typical of practically every Wisconsin farm. Now when the farmer goes into the field, there is just one thing paramount in his mind and that is getting as much work done as possible in the shortest length of time, and while he is naturally interested in efficiency, nevertheless he can sacrifice somewhat in efficiency in the way of saving of fuel, etc., to the greater advantage of getting that work done, and done on time.

Many of our farms are somewhat rolling and stony, and we do not view with favor the higher speeds which have been suggested as one way of utilizing the lower tractive ability of rubber tires. The increased liability of breakage would, in my estimation, more than offset the increased efficiency of rubber tire equipment as compared to using steel tires equipped with spade lugs and operated at lower speed.

The tractor we have has a maximum belt horsepower of about thirty-five and is usually able to pull three 14-in bottoms under average plowing conditions in this area. Under most of the conditions encountered this spring we found that two 14-in bottoms was the maximum practical load, and a two-bottom plow was used entirely in plowing the gardens referred to above. It was only under the most favorable of spring plowing conditions that we were able to satisfactorily pull three 14-in bottoms.

I can readily understand that rubber tires will decrease the rolling resistance of the tractor, and, in consequence, the fuel consumption of the machine, in so far as the ability of the wheel to hold the power will permit. However, just as soon as slipping begins to be present in any appreciable percentage, these gains are very quickly turned into losses. Another way in which we have summarized the situation is this: A tractor of the weight of our machine, but equipped with an engine of about 25 belt horsepower instead of 35, and built as of its present weight, would apparently be about right for rubber tire equipment. This, of course, is directly opposed to the present trend in tractor design.

Two other points which we have observed are these: First, that the rubber tire equipment packed the soil to a much greater extent when preparing the seedbed, that is,

[1]Professor of agricultural engineering, University of Wisconsin. Mem. A.S.A.E.

when disking, harrowing, etc., than did steel wheels properly equipped with extension rims. Second, the rubber tires are even more uncomfortable for the operator on rough ground than are steel wheels. The bouncing action of the rubber tires was almost disastrous to the operator on one or two occasions. I would refer here particularly to any operations that require crossing corn rows or working on any soil condition which was rather rough.

During part of our work the tractor was equipped with lugged chains, and when so equipped it gave a good account of itself, but I would question very much the economy or practicability of this equipment for regular field work. It will be necessary to gather data over a considerable period of time before we are able definitely to establish the economic practicability of this equipment. The data will have to include items of first cost, depreciation, and repairs of the tires, as well as the chains.

From all information which we can gather, the cost of a tractor equipped with rubber tires and chains will be very materially higher than the cost of a tractor equipped with steel wheels and lugs. Furthermore, it appears to me that the depreciation of rubber equipment will be much higher than that of the steel equipment, and I doubt very much whether the rubber equipment will reduce the depreciation in the transmission and engine, which I believe has been suggested by some. I am inclined to believe that the interest on the increased investment plus the higher depreciation will equal, if not offset, the gain in economy and fuel consumption. However, as stated above, it will require additional time to prove or disprove this contention.

The price of farm operating equipment has always been more or less an item of contention in the merchandising thereof. This has been particularly true during the last ten or twelve years, or since 1921, and I am convinced it will continue to be true for some time to come, and to undertake to merchandise an article at a higher price than they have been accustomed to pay will certainly take some real salesmanship and will require that the equipment must very materially outperform the equipment which they can purchase at a lower price.

So far I have not mentioned the use of the tractor on the highway. Obviously the pneumatic tire equipment is ideal for these conditions and needs no discussion, and the same thing may be said in general for the use of the tractor in the hayfield and the grain field. However, under our conditions these are minor, although in some cases rather important factors. Plowing and seedbed preparation is the major consideration.

In conclusion, we have sized up the proposition in this way: For the man who has considerable custom work to do, such as threshing, silo filling, or other work that takes him on the highway, this equipment would be of great value and very probably would be the equipment for him to purchase. The advantages of rubber tire equipment under these conditions would more than offset the disadvantages of the rubber tire equipment for field conditions. On the other hand, for the man who has work on his own farm only to do, or where practically all of it is confined to his own farm, we believe that the steel tire equipment would be economically and mechanically superior to rubber tire equipment. Just where the dividing line would be between these two groups is hard to say at the present time, and it will require at least another year or two of experience in the hands of many users before more definite conclusions can be arrived at.

# Wheel and Bearing Equipment for Farm Wagons and Trailers[1]

By E. A. Silver[2]

WITHIN THE PAST few years wheel equipment for tractors has changed considerably until we are now witnessing a trend toward the use of rubber tires on tractors. Without question rubber tires for tractors have many advantages over the steel wheel for farm use. First and foremost is the fact that the tractor can now be used on the highways without interference from the highways authorities; the task of removing and replacing wheel lugs is eliminated. Greater speed can be obtained, and the wear and tear on the tractor is greatly reduced due to the cushioning effect of the low-pressure pneumatic tire.

One important factor in reducing the cost of each day's service of any machine is to use it a greater number of days per year. In other words, increase the utility value of the machine and depreciation is lowered. With rubber tire equipment the tractor will undoubtedly be used for transportation purposes to a greater degree than in the past. A large part of the transportation work which was originally done by some other means, and necessitating an additional investment, will be done by the rubber-tired tractor. Indications point that it will be possible to travel at least 25 miles per hour on paved highways.

Wagons or trailers, with the rubber-tired tractor as a means for motive power, will undoubtedly become more common. In many cases the ordinary farm wagon may be brought into further use. Hard-surfaced roads, however, are extremely hard on machines equipped with steel wheels as well as creating a further danger of damaging the transported product. It seems, therefore, in order to secure the most out of rubber tire equipment for tractors, that wagons and trailers should be so equipped in order to meet the higher speeds in transportation work. With this in view the department of agricultural engineering of the Ohio Agricultural Experiment Station, in cooperation with the wagon wheel and rubber tire manufacturers, conducted a very exhaustive study on the draft of wheel equipment for farm wagons and trailers.

Several types of wheels and bearings were used, specifications of which are shown in the accompanying tables. These wheels were tested over five tractive surfaces: meadow, cultivated soil, cinder, gravel, and concrete roads. The rates of travel ranged from 2½ to 20 mph (miles per hour), depending upon the tractive surface over which the load was transported. The net loads varied from 2,000 to 5,000 lb.

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers at Chicago, December 1933.

[2]Agricultural engineer, Ohio Agricultural Experiment Station. Mem. A.S.A.E.

SPECIFICATIONS FOR WOOD AND STEEL WHEELS

| Type of Wheel | Diameter (inches) Front | Diameter (inches) Rear | Rim width (in) | Type of bearing | Weights per set of four (lb) |
|---|---|---|---|---|---|
| Wood | 40 | 44 | 3 | Wagon skein | |
| Wood | 44 | 44 | 4 | Wagon skein | |
| Steel | 28 | 34 | 4 | Wagon skein | 260 |
| Steel | 28 | 34 | 4 | Roller | 296 |
| Steel | 28 | 34 | 5 | Roller | 350 |
| Steel | 28 | 34 | 6 | Roller | 390 |
| Steel | 28 | 34 | 5 | Plain | 354 |
| Steel | 32 | 36 | 5 | Roller | 386 |
| Steel | 32 | 36 | 5 | Taper roller | 382 |

SPECIFICATIONS FOR RUBBER-TIRED WHEELS

| Type of wheel | Size | Inflation (lb) | Type of bearing | Weights (per set of four) (wheels and tires), lb |
|---|---|---|---|---|
| Solid cushion tire | 30x6.00 | | Roller | 640 |
| High-pressure pneumatic tire | 30x5.00 | 60 | Roller | 480 |
| Low-pressure pneumatic tire | 31x7.50 | 30 | Roller | 292 |

With the equipment at hand it was possible to get the following relationships:

1 The relative draft of various loads at various speeds on the five tractive surfaces

2 The relative draft of steel and rubber tire equipment for wagons or trailers over these five tractive surfaces, together with their effect on soil compaction

3 Diameters and widths of rim with reference to draft and soil compaction

4 The effect of plain, roller, and wagon skein type of bearings on the draft of the wagon.

Throughout all of the tests the wagon hitch was adjusted vertically in order to compensate for the various heights of wheels and tractive surfaces. This was accomplished by making a series of hitch tests in order to determine the true line of draft of the wagon.

Naturally the cultivated soil required the greatest draft, followed in order by meadow, gravel, cinder, and concrete roads. Much depends, however, on the condition of gravel and cinder roads, with respect to the draft required. If the surface of a gravel road contains many loose pebbles, the draft of the steel wheel will mount very rapidly, while the low-pressure tire is not affected to such a great extent.

On four of the five tractive surfaces and at all loads and rates of travel, the low-pressure pneumatic tire required less draft than any of the other types of wheels tested. The only exception was on concrete road where there was very little difference between the steel wheel and the low-pressure pneumatic tire. The greatest difference in draft between the low-pressure pneumatic tire and the steel wheel occurred on gravel roads. To move a gross load of 6,000 lb at the rate of 2½ mph, the low-pressure tire required an average of 58 lb, while the steel wheel required an average of 179 lb pull. This is more than a 200 per cent increase. The reason for this is that a load mounted on steel wheels must be partially lifted over stones and irregularities on the road surface, while the rubber tire will be compressed by these same irregularities, thereby eliminating any noticeable rise to the load itself.

The importance of wheel diameter depends largely upon the tractive surfaces over which the load is transported. In cultivated soil, however, the smaller diameter wheels required more draft ranging from 1 to 16 per cent more and depending upon the weight of the load transported and the rate of travel. On hard-surfaced roads or even in meadow, very little difference in draft was noted.

The width of rim seems to be a factor in cultivated soil only. With loads weighing from 5,000 to 6,000 lb, the 6-in rim gave a slight advantage. The 5-in rim excelled at all loads weighing below 5,000 lb. The soil, however, was in a fairly dry state and different results might be expected if the soil were in a wet condition. No advantage in draft existed with the narrow 3-in rim.

Wheels equipped with roller bearings show a decided decrease in the draft of the wagon. On cinder road the wagon skein type of bearing required the greatest draft, while the taper-roller bearing required the least.

PERHAPS NO RECENT ENGINEERING DEVELOPMENT IN MECHANICAL FARM EQUIPMENT HAS EXCITED SUCH KEEN INTEREST, EVEN ENTHUSIASM, AS HAS THE APPLICATION OF PNEUMATIC RUBBER TIRES TO FARM TRACTORS AND OTHER MACHINES, INCLUDING WAGONS AND TRAILERS

# Farm Tests of Low-Pressure Tractor Tires[1]

By Fred W. Hawthorn[2]

AS AN AGRICULTURAL engineer actively engaged in farming I have been requested to discuss low-pressure rubber tires from the standpoint of a farm machine user. The crudeness of my experiments through lack of elaborate testing apparatus may be somewhat offset by the fact that these tests represent the actual operation of farm implements under typical field conditions.

These tests were run with a Minneapolis-Moline tractor used on our farm last year in connection with other experimental work. The rubber-tire equipment was not available until September so I had opportunity to make only comparative tests in plowing and in disking over this plowed ground. Conventional type steel wheels with 3½-in spade lugs were tested against 9x36 Goodyear tires inflated to 12 lb and equipped with 300 lb of additional weights per wheel. Rubber tires were not available for the front wheels. Governor and carburetor adjustments were not changed during tests. With the motor warmed up and everything operating normally, the small fuel tank was cut in for a test run of exactly one hour. The fuel used was competition grade gasoline, and consumption was determined by careful refill measurements. Miles and acreage covered in the hours run were computed from front-wheel hubodometer readings.

In the following fuel economy tests the tractor was operated in the highest gear in which the motor would carry the load and maintain normal speed. The first tests were on unplowed medium clay loam soil pulling a two-bottom plow set to cut 30 in at a depth of 6½ in. The last two tests were run on recently plowed ground with a 14-ft single disk, angled quite sharply, as a load. The results were as follows:

| | Miles per hour | Acres per hour | Gasoline, gal per hour | Gasoline, gal per acre | Gain in speed, % | Fuel saving, % |
|---|---|---|---|---|---|---|
| Steel wheels, 3rd gear, plow load 6½ in deep | 3.40 | 1.03 | 1.93 | 1.87 | | |
| Rubber tires, 4th gear, plow load 6½ in deep | 3.95 | 1.19 | 1.79 | 1.50 | 16.2 | 19.8 |
| Steel wheels, 2nd gear, 14-ft disk, plowed ground | 2.8 | 4.75 | 1.85 | 0.390 | | |
| Rubber tires, 4th gear, 14-ft disk, plowed ground | 3.9 | 6.62 | 1.89 | 0.286 | 39.3 | 27.0 |

In the plowing tests it was noticed that the engine handled the load much easier in fourth gear with rubber tires than in third gear with steel wheels. However, in the disking tests on plowed ground, fourth gear with rubber tires gave the engine a somewhat heavier load than second gear with steel wheels. This change through two speeds perhaps is the main reason why the advantage of rubber tires showed up considerably better in the disking tests.

Other tests were made to get data on the maximum drawbar pull obtainable in the different gears with steel wheels as compared to rubber tires. The tests were made on well-compacted pasture land covered with a thick growth of rag weed about a foot high. Maximum plowing depth was determined by dropping plows to the last notch in which the engine would carry the load at rated speed. The low gear tests were not very satisfactory, as with both wheel equipments the maximum depth was more governed by the ability of the plows to scour at this abnormal depth than by the available drawbar pull.

| | 1st gear | 2nd gear | 3rd gear | 4th gear |
|---|---|---|---|---|
| Maximum plowing depth, steel wheels, two 14-in plows | Notch 13<br>10 in | Notch 9<br>8½ in | Notch 5<br>6½ in | Notch 3<br>5 in |
| Maximum plowing depth, rubber tires, two 14-in plows | Notch 13<br>10 in | Notch 11<br>9½ in | Notch 9<br>8½ in | Notch 6<br>7 in |

These tests show that the gain in maximum drawbar pull as indicated by maximum plowing depth varies from a stand-off in low gear to two inches in favor of rubber tires in the two highest gears. Rubber tires pulled as much in third gear as steel wheels in second gear, and pulled the plows a half inch deeper in fourth gear than was possible in third gear with steel wheels.

When disking on fall plowing I found that with considerable slippage the tractor, when equipped with rubber tires, would just pull a 19 per cent grade in second gear, while with steel wheels it was impossible to make this grade even in low gear as the drivers would dig down.

I had a good opportunity to observe the comparative performance of steel wheels and rubber tires when plowing on hills. Steel wheels required second gear to pull plows 5½ in deep up a 16 per cent grade while with rubber tires I could just make this grade in fourth gear at the same depth, and in second gear with some slippage I could make the grade at 7 in plowing depth. If steel wheels are allowed to slip much on a hill, the land wheel of the plow will sink excessively deep into the soil loosened by the drivers and a stall will soon result. Rubber tires have a distinct advantage here, as they may slip considerably without affecting the surface soil to any extent.

While plowing on a 23 per cent side slope with steel wheels, I found that, if the tractor were driven in a furrow over 5½ in deep, it would be tipped at such a sharp angle that the upper driver would spin, or else the front wheels would skid down the hill. To my surprise no such difficulty was encountered when using rubber tires, even when driving in a 7-in furrow. Furthermore, instead of having to incline the front wheels sharply up the hill to hold the tractor in place, as was the case with steel wheels, the tractor was steered almost the same as if operating on level ground. Apparently the greater rolling resistance of the lower drivewheel is a big factor in dragging the front end of the tractor down the hill, having the same effect as the application of the lower wheel brake. Rubber tires reduce this difference between the rolling resistances of the upper and lower drivers to such an extent that little effect on steerage is noticeable.

(Continued on page 63)

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers, at Chicago, December 1933.

[2]Farmer, Monona County, Iowa. Mem. A.S.A.E.

# Pneumatic Tires vs. Steel Wheels for Tractors[1]

By R. H. Wileman[2]

I WOULD LIKE to point out that in securing the data presented in this paper no attempt was made to get maximum drawbar pull from the tractor or to compare the pull at various tractor speeds with different wheel equipment. These tests were made during the performance of various field operations under prevailing weather and soil conditions with the tractor operating at a speed which was considered to give its best performance in handling the load placed behind it.

The first series of data was secured with a three-plow, general-purpose tractor during the production of 100 acres of corn the past season.

The steel wheels were standard 42-12-in with 5-in spade lugs on the rear, with 25-4-in plain wheels with skid ring in front.

The rubber equipment consisted of 11.25 x 24 rear tires carrying 12 lb pressure and 6.00x16-in front tires inflated to 20 lb pressure.

When equipped with the regular steel wheels and lugs pulling a three 14-in bottom plow 7 in deep in sod ground, the tractor handled the load in third gear at an average speed of 3.53 mph (miles per hour). The soil ranged from clay to black gumbo. The latter would pull the motor speed down slightly in places. The average drawbar power developed during the test was 14.36 hp with a maximum of 18.48 dhp (drawbar horsepower). The fuel consumption was found to be 2.6 gal per acre.

Changing to low-pressure rubber tires and pulling the same load it was found that the tractor could be operated in fourth gear at an average speed of 3.73 mph. The difference of only 0.2 mph between third and fourth gear was due to the smaller rolling circumference of the rubber tires. This was the maximum speed available with the standard tractor transmission. At this speed no reduction in motor speed was recorded even in the gumbo spots.

The average drawbar horsepower recorded was 17.33 with a maximum of 20.8. The fuel consumption was found to be 2.24 gal per acre. This is a reduction of 13.9 per cent over steel wheels and lugs.

The difference in fuel consumption and speed between the two types of wheel equipment can be explained by the power required to overcome the rolling resistance of the tractor itself. Under the conditions tested with the right wheel in the open furrow and the left wheel on the unplowed sod ground, dynamometer tests showed that 10.72 hp was required to move the tractor itself with steel wheels and lugs at a speed of 3½ mph. Under the same conditions 4.2 hp was required to move the tractor at the same speed when equipped with rubber tires. In other words, the rolling resistance was reduced 60.8 per cent by the use of low-pressure rubber tires.

Tests made with the same tractor equipped with a four-row cultivator gave a 20 per cent reduction in fuel consumption under the following conditions.

Two cultivations of a 40-acre field were made using the steel wheels and lugs to cultivate every other four rows. The alternating four rows were cultivated using the rubber tire equipment. For the second cultivation the areas cultivated with each type of wheel equipment were reversed. The average fuel consumption for cultivating 20 acres with rubber tire equipment was 6.45 gal as compared to 8.06 gal with steel wheels and lugs. The average time required to cultivate 20 acres with rubber tires was 3 h 12 min, and with steel wheels and lugs, 3 h 8 min. There was a noticeable difference in the ease of handling the tractor, especially in turning, in favor of the rubber tires.

The use of wheel weights was not found necessary, except in heavy plowing, and then usually only on the land wheel. In preparing the seedbed, even when pulling loads up to the capacity of the tractor, in planting, cultivation, or harvesting operations under the soil conditions encountered, wheel weights were not needed.

In plowing sod where there was quite a heavy growth and after a shower, or when the surface was sticky on corn stalk ground, it was found necessary to use skid chains to secure sufficient traction with the rubber tires.

This tractor equipped with low-pressure pneumatic tires has performed 340 h of field work in the production of 100 acres of corn during the past season. The rubber tires were used exclusively, except when replaced with the steel wheels and lugs in securing the above data. With this amount of use no appreciable wear of the tires is evident and no tire trouble has been experienced.

Comparative tests made with a one-plow general-purpose tractor under 1933 fall plowing conditions of stubble ground.

The steel wheels were standard 54x6-in with 4-in spade lugs on the rear, with a single 23x6-in front wheel with integral skid ring.

The rubber tire equipment consisted of 9.00x36 rear tire and a 7.50x10 front tire.

A single-bottom, 18-in plow was used for the load during these tests. The plow was set to a depth so that the tractor motor would just maintain its governed speed at the place in the field where the resistance of the plow was greatest.

Operating in high gear with steel wheels and lugs the plow was cutting from 6 to 6½ in deep with the tractor developing 8.08 dhp. When the wheels equipped with rubber tires were put on in place of the steel wheels and lugs, the plow was lowered to cut from 7 to 7½ in deep to place the same load on the tractor motor. The dynamometer then showed a drawbar horsepower of 9.33 with no increase in power developed by the motor. This difference in drawbar horsepower can be explained by the difference in rolling resistance of the tractor itself when equipped with the two types of wheels. The amount of power required to move the tractor itself was found to be 3.655 hp with steel wheels and lugs, and when equipped with rubber tires 2.08 hp.

Fuel economy tests were made in both high and second gear using the same plow setting for both types of wheels, thus maintaining as nearly as possible a uniform load.

With steel wheels and lugs and the tractor running in high gear at an average speed of 3.41 mph, 14 lb or 2.25

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers at Chicago, December 1933.

[2]Agricultural engineer, Purdue University. Assoc. Mem. A.S.A.E.

gal of fuel were used per acre. With rubber tire equipment the speed was 3.31 mph and used 12 lb or 1.935 gal of fuel per acre, or 14.3 per cent less fuel was used by the tractor when equipped with rubber tires operating in high gear.

In second gear using steel wheels and lugs 14.66 lb or 2.36 gal of fuel were used per acre with a speed of 2.87 mph, as compared to 14 lb or 2.26 gal per acre with rubber tires, or a difference of 4.5 per cent.

Neither wheel weights nor skid chains were used during the tests made with the small tractor.


## SUMMARY

These comparative tests of steel wheels and lugs versus low-pressure pneumatic tires made under actual field working conditions as previously outlined show the following points:

1 When equipped with pneumatic tires, the tractor pulled the same load at a faster speed than when steel wheels were used.

2 The amount of fuel required for plowing was reduced 13.9 per cent with the large tractor and 14.3 per cent with the small tractor in high gear by the use of pneumatic tires.

3 With low speeds and heavy loads the amount of fuel saved by pneumatic tires over steel wheels is considerably reduced.

4 The power consumed to overcome the rolling resistance of the tractor itself when equipped with pneumatic tires was reduced 60.8 per cent for the large tractor and 43 per cent for the small tractor.

5 A saving of 20 per cent in fuel was secured by the use of pneumatic tires for cultivating.

6 In plowing sod with considerable growth, or when the surface was slick, the use of skid chains was necessary to secure sufficient traction.

7 Although not measured, the operator readily noticed a greater ease of handling and riding qualities of the tractor when equipped with pneumatic tires.

# Farm Tests of Low-Pressure Tractor Tires

(Continued from page 61)

I had no way of definitely measuring soil packing, but I cannot agree with enthusiasts who claim that rubber tires do not pack the soil. They may not pack quite as firmly, but, on the other hand, there are no lugs to tear up the soil after passing over it, as in the case of steel wheels, so the final result is perhaps not far from a stand-off. An open type wheel causes the least soil packing, but under many conditions tractor efficiency is reduced by the high rolling resistance of this kind of wheel.

While rubber tires add much to the easy-riding qualities of a tractor, I think the greatest contribution to the comfort of the operator is in the matter of greatly reduced field dust. I recently disked a field of bone-dry plowing in a cross wind of gale intensity and was very comfortable without using goggles. Had steel wheels been used goggles would have been a necessity, and I would have been "spitting mud" for days afterward. Only those who have operated a tractor day after day in dusty fields can fully appreciate this point.

I have been discussing mainly the good points of rubber tires. Although I have not experienced them, I presume there are disadvantages. It is quite obvious that traction would be unsatisfactory on a muddy surface or on melting snow or ice. Just as with a car special chains would be necessary under such conditions. Then there is the possibility of punctures and inflation at rather infrequent intervals is necessary to take care of natural leakage. But the biggest question no doubt is the initial cost, depreciation, and maintenance of rubber tire equipment, and the relation of these items to saving of fuel, increase of capacity, saving of wear and tear on the tractor, etc. I cannot intelligently discuss this economic phase of the subject as I do not know how long a tractor tire will last.

In summing up my experiments with rubber tires, I would say that a rubber-tired tractor will turn out around a quarter more work in a given time than the same machine equipped with steel wheels, and this with a corresponding fuel saving. When working on hills rubber tires not only add greatly to the surplus power so badly needed on steep grades, but they also materially improve the steering and general handleability of the tractor on steep side slopes. The ability of the rubber-tired tractor to travel at high speeds over hard-surfaced roads should open up possibilities of use as a hauling unit. Last but not least, rubber tires add much to the personal comfort and pleasure of tractor operation.

The two sources of farm power, horses and tractors, have now reached an unbelievable state of depletion and insufficiency. . . . . The machine age in agriculture is not passing; it is just commencing, and I predict that when and if this lost buying power is again restored to the farmers, they will buy tractors as well as all other farm equipment in larger quantities than ever before, and I think most of them will want tractors equipped with rubber tires. If I were buying a tractor today, in view of my brief experiences, I would choose rubber tires as regular wheel equipment.

# Rubber Tires on Tractors and Cane Wagons[1]

By Harold T. Barr[2]

THE WIDER USE of tractors on Louisiana sugar cane plantations has been held back because of their limited use during the rainy season. The number of mules per plantation has been governed by the number required during the harvest season, and in most cases this number was great enough to furnish all the needed power for the balance of the year. The soil in the sugar cane belt varies from sandy to an extremely heavy gumbo, with an average rainfall of 15.6 in during the harvest season.

In the early part of 1932 sets of low-pressure balloon tires were installed on experimental wagons, one set at the Louisiana agricultural experiment station at Baton Rouge, and the other set at Southdown plantation at Houma. These tires were of the type referred to by many as "doughnut" tires, 30x13 tires being used on the front and 35x15 on the rear, with two-thirds of the load on the rear tires. Comparing these tires to steel wheels with 4-in rims with 34-in diameter on the front and 54-in diameter on the rear, with a 2-ton load, the draft ranged from one-third to one-half less for the rubber tires. When the steel wheels cut in 6 to 10 in in the cane field, the rubber tires cut in 2 to 4 in, with a saving of 40 to 50 per cent in draft. With water standing in the field the rubber tires cut in from 4 to 6 in, with the cane trash and soft mud often building up ahead of the tires until it was necessary to stop and remove the trash. The same trouble was experienced with tread-type wagons.

On the heavy gumbo soils, wher the mud became stiff, it would build up until the wheels could not turn. Scrapers proved unsuccessful. Burlap and tire breaker strip fabric were each fashioned into overshoes for the tires. The fabrics each caused the mud to shed, but would last only two hours before being worn out. The tread rubber has been removed exposing the breaker strip on one tire to test out its mud shedding and wearing qualities.

Two two-wheel cane carts are now in use on the Southdown plantation, each being equipped with two-tractor type, 9.00x36 (54-in outside diameter) low-pressure tires. With the larger tires the trash and mud does not build up ahead as was experienced with the smaller outside diameter tires. The larger tires are being operated at speeds varying from 4 to 8 mph (miles per hour). At the higher speeds the mud throws off and does not build up as on the smaller tires.

A general-purpose tractor with tractor-type, 9.00x36 tires is being used in pulling the two rubber-tired cane carts. This tractor has a 6 ft 6-in front and rear tread, with the rubber tires only on the rear wheels. A second tractor of the same make and tread, except equipped with 6-in offset steel lugs, is operating in the same field pulling one cane wagon equipped with 4-in steel wheels. Less than the average amount of rain has fallen during the present season and the hauling question is relatively simple. With dry conditions on a haul of 8400 ft per round trip, the rubber-tired tractor and wagons hauled 80 tons per 10-hr day, as compared to 40 tons per 10-hr day with the steel wheel wagon and steel wheel tractor, and 20 tons per 10-hr day with the four mule wagons. In the mud on a haul of 6000 ft per round trip, the same tonnage was hauled per 10-hr day. The rubber-tired tractor used lug-type chains in the mud. The tractor made a round trip in 14 minutes and the mule wagons in 38 minutes, excluding loading. The tractors were at a certain disadvantage as they were working in a unit of 9-4 mule wagons, and lost some time in the field. A rain of 1.9 in on November 19, and 2.1 in on November 21, had made the fields soft so that on November 22 the 4-in steel wagon wheels cut in from 4 to 6 in; the rubber tires cutting in from 1 to 2 in. During the harvest of 1929 the rainfall was approximately twice the average, with wagons cutting in from 12 to 20 in. Several plantations lost thousands of dollars during the 1929 season because of their inability to get the crop harvested on time. What rubber-tired equipment will do under those conditions, we are keenly interested in knowing.

A general-purpose tractor was equipped with 9.00x36 rear and 6.00x16 front tires and tested on the drawbar at the Louisiana State University. The load was gradually increased until the wheels slipped badly or the maximum engine power was reached. On dry Bermuda grass sod and dry ground, the tires held more than the engine could pull; in dry soybean stubble with a small amount of grass, the maximum pull with 12 per cent wheel slippage was 100 lb under that on the dry sod. On a heavy growth of green weeds in corn stubble, the maximum pull was only 50 per cent of that of the dry sod. No chains were used.

A test was made with a general-purpose tractor pulling a 20-in plow 6½ in deep in a heavy black soil. With 5-in spade lugs on a 12-in wheel, dirt filled in to within one inch of the tips of the lugs on the furrow wheel after 30 min of plowing. After filling in the furrow wheel gave considerable slippage. The steel wheels were removed and the 9.00x36 tires and wheels put on. With the rubber tires no noticeable slippage could be observed and the treads remained clean.

The writer has visited three plantations and has the data from three more where rubber-tired tractors were tried out. Two of the six are satisfied with the tires. The other four were discouraged by one or all of the following factors: (1) The tires have a tendency to slip on the headland when a light dew has fallen; (2) the clearance of the tractor is reduced; (3) the tread of the tractor is increased —all of which are disadvantages. Another reported that they endeavored to haul cane in the mud, but the tractor was unable to go in the cut with an empty wagon. Later they tried weed chains with large lugs in the rice field, but without success. On another plantation which the writer visited, the valve stems were repeatedly torn from the tubes.

From our observations this latter trouble was caused by too low pressure and the turning of the tractor very short at high speed under a fairly heavy pull.

The writer believes that rubber tires have merit, but that the tires should not be tried out or sold indiscriminately. Tractor and tire dealers should be more careful in supplying the correct wheels, tires, and chains for each model of tractor, and then see that they are being properly used; otherwise a mountain of adverse criticism will be built up which it will be hard to climb over.

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[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers, at Chicago, December 1933.

[2]Agricultural engineer, Louisiana Agricultural Experiment Station. Mem. A.S.A.E.

# Idaho Drawbar Tests of Rubber Tires[1]

By Hobart Beresford[2]

THE OBJECT of this study was to determine what effect different types of traction wheels would produce on maximum drawbar developed by a wheel-type tractor when used on different soil surfaces.

The two types of traction wheels tested were steel and low pressure rubber tires. The rubber tires were tested on (1) grass, (2) hard, graveled road, (3) pavement, and (4) soft, loose oat stubble. The steel wheels were tested only on grass sod and oat stubble.

Equipment used during this test consisted of a 10-20 McCormick-Deering wheel tractor, a Quad truck used to load the tractor, an hydraulic dynamometer, two 150-lb wheel weights, two steel traction wheels, and two rubber-tire-equipped traction wheels. The steel wheels measured 42 in in diameter by 12 in wide. Each wheel was equipped with forty spade lugs 4 in high, 3½ in wide, and a 5¾-in base. The rear pneumatic tires were 11.25-24 inflated to 12 lb per square inch pressure, while the front tires were 6.50x16 and were inflated to 16 lb per square inch pressure.

The hydraulic dynamometer was hitched between tractor and load and registered the pull directly in pounds. An old Quad truck was used to load the tractor and any desired load could be obtained and held constant during the trial.

Drawbar readings were taken just as slipping occurred and this reading recorded as maximum drawbar pull for that gear position. Per cent of wheel slippage was determined by comparing the distance advanced by the tractor with and without load in ten revolutions of the drivewheels. The slippage determined in this manner is made up of two factors, one being actual slippage, and the other resulting from the shorter distance traveled by the tractor in a given number of revolutions owing to the fact that the effective drivewheel radius is decreased when the tractor is loaded. In the case of pneumatic tires the drivewheel radius decreases as the tractor is loaded, resulting in an increased width of tread on the ground and a shorter advance for a given number of revolutions of the drivewheels. With spade lug wheels the tractor rode high on the point of the lugs under no load, while under load the lugs sank deeper in the ground thus decreasing the drivewheel radius and hence the advance in a given number of revolutions.

An inspection of the accompanying table shows that the no-load distance traveled by the tractor in ten revolutions of the drivewheels, when equipped with pneumatic tires on the four surfaces, was approximately the same; however, the distance traveled with cleated wheels was considerably greater than with pneumatic tires at no load. With a dynamometer reading of 1,000 lb, for the same gear and surface conditions, the slippage of the pneumatic wheels on the sod surface was 3.67 per cent in one trial and 6.45 per cent in another, as compared to 2.84 per cent for the spade lug equipped wheels. On the same field for third gear operation the spade lugs had the advantage over the rubber-tire-equipped wheels by 400 lb and also show a much lower percentage of slippage than does the pneumatic tires. During this latter trial the tread width of the pneumatic tires increased from 12 to 13 in.

On the softer oat stubble there is a slight advantage in

(Continued on page 68)

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers, at Chicago, December 1933. Approved by the Director of the Idaho Agricultural Experiment Station as Research Paper No. 115.

[2]Professor of agricultural engineering, University of Idaho. Mem. A.S.A.E.

DATA FROM THE IDAHO TRACTOR FIELD TESTS*

| Test No. | Gear position | Distance traveled in feet by tractor in 10 revolutions of drivewheels: No load | With load | Dynamometer reading at slipping point of wheels, lb | Per cent apparent slippage | Width of tread, in | Per cent increase in width of tread due to load | Surface conditions |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 111.6 | 104.4 | 1000 | 6.45 | 12 | 0 | grass sod |
| 2 | 2 | 111.6 | 107.5 | 1000 | 3.67 | 12 | 0 | grass sod |
| 3 | 3 | 111.6 | 90.4 | 1800 | 19.00 | 13 | 8.34 | grass sod |
| 1 | 1 | 112.3 | 108.4 | 500 | 3.47 | 12 | 0 | hard road |
| 2 | 2 | 112.3 | 94.5 | 2000 | 15.82 | 12½ | 4.17 | hard road |
| 1 | 2 | 111.7 | 99.8 | 1300 | 10.65 | 12 | 0 | oat stubble |
| 2 | 2 | 111.7 | 93.6 | 1700 | 16.20 | 12 | 0 | oat stubble |
| 1 | 2 | 111.0 | 107.0 | 1200 | 3.61 | 13 | 8.34 | pavement |
| 2 | 2 | 111.0 | 96.4 | 2600 | 13.15 | 13 | 8.34 | pavement |
| | | | | Increased Weight on Wheels, 300 lb | | | | |
| 1 | 2 | 111.7 | 95.2 | 2000 | 14.8 | 13½ | 12.50 | oat stubble |
| 2 | 2 | 112.3 | 97.9 | 2200 | 12.8 | 13 | 8.34 | hard road |
| | | | | Steel Wheels | | | | |
| 1 | 2 | 133.7 | 129.9 | 1000 | 2.84 | 10 | 0 | grass sod |
| 2 | 3 | 133.7 | 123.7 | 2200 | 7.50 | 10 | 0 | grass sod |
| 1 | 2 | 132.5 | 125.2 | 1400 | 5.50 | 10 | 0 | oat stubble |
| 2 | 3 | 132.5 | 123.8 | 1800 | 6.60 | 10 | 0 | oat stubble |

McCormick-Deering 10-20 tractor
Transmission, 2-3-4 mph forward; 2¾ mph reverse
Rated speed, 1025 rpm
Pneumatic tire size, rear 11.25x24; front 6.50x16
Steel wheel size: 42x12 in. Each wheel equipped with 40 spade lugs 3½ in wide, 5¾ in at the base, and 4 in high

*The author was assisted in the compilation of the data by J. B. Rodgers, graduate assistant in agricultural engineering, University of Idaho.

# Plowing with Rubber-Tire-Equipped Tractor[1]

By A. J. Schwantes[2]

IN THE SUMMER of 1933, a study was made by the Division of Agricultural Engineering, University of Minnesota, of the performance of a wheel type tractor equipped with standard steel wheels and lugs, with pneumatic tires and with zero-pneumatic or cushion rubber tires. For this comparative test a Twin City Model KT tractor was used in plowing a field of about 12 acres. The field was divided into four plots. One of the plots was reserved for preliminary testing work to make possible a proper adjustment of the plow and of the load to the capacity of the tractor with each set of equipment. Of the three remaining plots, plot A was plowed with the use of standard 12-in steel rims equipped with 4-in spade lugs; plot B was plowed with 11.25x24-in pneumatic tires on the drivewheels of the tractor and pneumatic tires on the front wheels; plot C was plowed with 12x46-in cushion-rubber tires on the drivewheels and the same pneumatic tires that were used in plowing plot B on the front wheels.

The wheel equipment that was used in plowing plot B included the standard low-pressure pneumatic tires that have been developed especially for use on farm tractors. The equipment used on plot C was the so-called "zero-pressure" or cushion rubber tire which is an interesting recent development for farm tractor use. This latter type of tire, as the name implies, has no air in it, and yet it is not a solid rubber tire. It has a certain amount of flexibility and its performance appears to compare very favorably with the standard pneumatic rubber tire.

Data from a Comparative Plowing Test Using the Same Tractor Equipped with Pneumatic Tires, Zero-Pressure Tires, and Steel Wheels and Lugs

| Plot designation | A | B | C |
|---|---|---|---|
| Wheel equipment | steel | pneumatic | zero pressure |
| Plot area, acres | 2.38 | 3.33 | 2.73 |
| Fuel, gallons per acre | 3.05 | 1.95 | 2.29 |
| Fuel, gallons per hour | 2.56 | 2.12 | 2.23 |
| Rate of travel, mph | 3.33 | 3.18 | 3.21 |
| Slippage, per cent (land wheel) | 8.00 | 5.75 | 8.80 |
| Slippage, per cent (furrow wheel) | 6.90 | 4.15 | 8.50 |
| Number of 14-in plows | 2 | 3 | 3 |
| Depth of plowing, inches | 7.17 | 6.60 | 6.60 |
| Draft, pounds | 1220 | 1660 | 1655 |
| Horsepower | 10.83 | 14.08 | 14.19 |
| Horsepower-hours per acre | 12.60 | 11.92 | 13.25 |
| Horsepower-hours per gallon | 4.14 | 6.11 | 5.78 |

The accompanying table contains a summary of a large part of the data obtained in these tests. It should be remembered that these data represent the results of comparative tests on one plot only and that the plot was relatively small. No doubt there are reflected the effects of certain peculiarities of the particular plot, and similar tests on another plot possessing different characteristics would probably give results somewhat different. In the main, however, it is felt that the results indicate very definitely certain fundamental differences in the performance of a tractor equipped with rubber tires and one equipped with steel wheels and lugs.

In each case the tractor was loaded to about its optimum capacity. With each set of wheel equipment, the plow was gradually set deeper until a point was reached where the engine was stalled or the wheels would slip excessively. The plow was then raised just enough to allow the tractor to move along throughout the entire length of the field without apparently being overworked.

All of the plowing was done in intermediate speed. The slightly higher rate of travel observed when the steel wheel equipment was used is no doubt the result of the load being slightly less in proportion to the ability of the tractor to handle it than was the case with rubber tires. The slippage of the drivewheels with pneumatic tires under conditions of this test was less than that with steel wheels. The test was conducted with weights totaling 280 lb added to the furrow wheel and 420 lb added to the land wheel on plots B and C. The air pressure in the pneumatic tires was 12 lb. The slippage when zero-pressure tires were used was greater than with the use of pneumatic tires.

It is significant that the fuel requirement per acre was reduced by about one-third when rubber tires were exchanged for steel wheels. This is not a true and complete comparison of the efficiency of the two types of wheel equipment, because the land was plowed deeper on plot A than on plots B and C. A better comparison may be had from the horsepower-hours per gallon of fuel on each of the plots. The average number of horsepower-hours per gallon on plots B and C is 5.94. This is an increase of over 40 per cent more than that obtained on plot A. The difference in the efficiency of pneumatic tires and zero-pressure tires is not significant, at least in view of only one test, but there is a significant difference between the performance of the tractor when equipped with rubber tires and when equipped with steel wheels and lugs.

*Wheel Slippage with Rubber Tires.* One of the more important problems that presents itself in connection with the use of rubber tires on farm tractors is that of traction. Under ideal ground conditions, when the load on the tractor is not excessive, traction with rubber tires is at least equal to that of steel wheel equipment. The tire area in contact with the ground is a very important factor influenc-

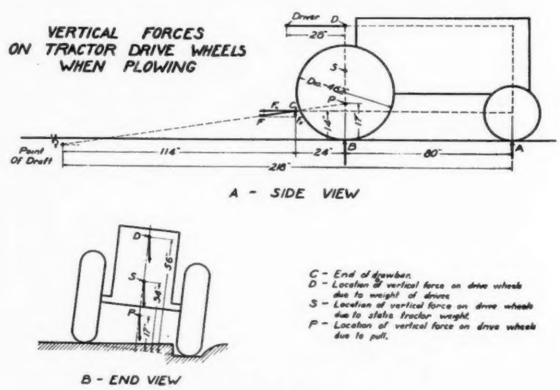
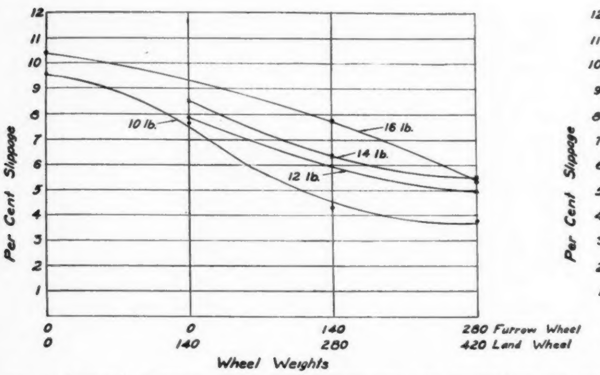



FIG. 1

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers at Chicago, December 1933. Approved by the Minnesota Agricultural Experiment Station as Journal Series Paper No. 1236.

[2]Associate professor of agricultural engineering, University of Minnesota. Mem. A.S.A.E.



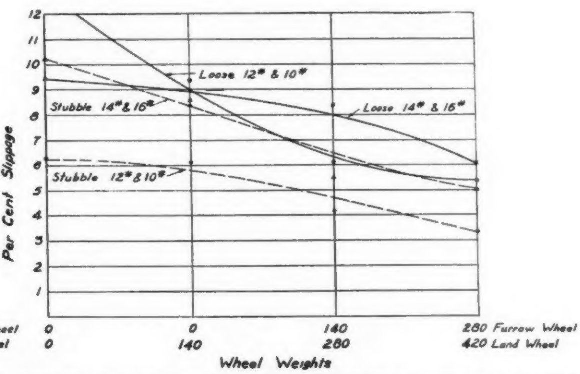




FIG. 2 (LEFT) EFFECT OF WHEEL WEIGHTS ON SLIPPAGE OF PNEUMATIC TIRES AT VARIOUS PRESSURES. FIG. 3 (RIGHT) COMPARATIVE EFFECT OF LOOSE GROUND AND STUBBLE LAND ON SLIPPAGE OF PNEUMATIC TRACTOR TIRES

ing traction. Hence, the amount of air pressure carried in the tires and the weight of the tractor are important.

To obtain some data with regard to the effect of air pressure and tractor weight on wheel slippage, a series of tests was conducted. The tests were conducted with 11.25 x 24-in pneumatic tires on the tractor while plowing. Slippage readings were made with 10, 12, 14, and 16-lb pressures and with various weights added to the tractor wheels at each pressure. The weights were added in increments of 140 lb and ranged in amount as shown in Fig. 2.

*Method of Determining Slippage.* The method of procedure in obtaining the field data was similar to that usually followed in determining slippage with steel wheel equipment. The tractor was driven over a given course in the field with one wheel in the furrow and the other on the land, but no load was attached to it. The number of revolutions of each drivewheel during this run was determined and noted. Four such courses were established on the plot, two on each side of the land. One-half of the field was a stubble field on which a small grain crop had been grown in 1932; the other half had been plowed and disked about a month before and consequently the land on this half was much looser than on the stubble field. On each side of the field was one course on loose ground and one on stubble land; a total of four courses for each time around the field.

After the no-load run had been made with the tractor, a run was made on both the loose ground and the stubble land courses with a given combination of air pressure in the tires and weights added to the wheels. A series was first run with a pressure of 16 lb, then with 14, 12, and 10 lb. In each series four different combinations of weights were used as indicated in Fig. 2. The number of revolutions made by each drivewheel over each course was determined by means of mechanical counters that were attached to the fenders and actuated by rods coming from an eccentric position near the hub of the wheel.

These data as such were useless for calculating slippage because of the effective radius of the drivewheels was different in each case. The effective radius is influenced by the air pressure in the tires and by the vertical load on the drivewheels. It is necessary accordingly to make some corrections to cover this situation.

It was felt that one of the most satisfactory methods of making such corrections would be to compute as accurately as possible the vertical forces acting on the drivewheels in each of the tests. With this information it was possible to determine the amount of deflection in each case and then the effective radius. The amount of deflection of a tire with a given air pressure for any given force was obtained from tables and graphs that had been prepared from laboratory tests by tire manufacturers. The effective radius was then compared with the effective radius (under the same conditions of air pressure in the tires) when the tractor was not pulling a load. This comparison furnished a correction factor, by means of which the number of revolutions made by the drivewheels was corrected to what it would have been had the radius of the wheel not been changed by the additional load due to the pull. The corrected number of revolutions was different from the number obtained on the same course, when the tractor was not pulling the plow, only to the extent of wheel slippage due to the load of the plow. With this figure the per cent of wheel slippage was determined.

Fig. 1 indicates the method used in determining the vertical forces on the drivewheels of the tractor. The weight of the tractor without wheel weights and without the driver is 4483 lb, distributed with 1565 lb on the front wheels and 2918 lb on the rear wheels. This force due to the static weight of the tractor is always present.

When the tractor was pulling the plow, the dynamometer reading was 1660 lb ($F$, Fig. 1A). Then $F_x$ and $F_y$ the horizontal and vertical components are 1646 and 204 lb, respectively. Taking moments about A, $(F_x \times 14) + (F_y \times 104) = B_p \times 80$, when $B_p$ = vertical reaction against drivewheels due to pull.

$$23044 + 21216 = 80\,B_p$$
$$44260 = 80\,B_p$$
$$B_p = 553 \text{ lb}$$

Considering the effect of the weight of the driver (150 lb) on the drivewheels, $150 \times (80 + 28) = B_d \times 80$, when $B_d$ = vertical reaction against drivewheels due to the driver

$$16200 = B_d \times 80$$
$$B_d = 203 \text{ lb}$$

The sum of the forces acting vertically on the drivewheels when the tractor is being driven, but when no load is pulled and no additional weights are added to the drivewheels, is $2918 + 203 = 3121$ lb. When the plow is pulled, 553 lb must be added making a total of 3674 lb.

Because the land wheel usually tends to slip more than the furrow wheel, data were kept on the performance of each wheel in the field tests. Because the tractor is leaning when plowing with one wheel in the furrow, it is evident that the vertical forces through the rear axle of the tractor are not equally distributed on the two drivewheels. Fig. 1B illustrates the method used in determining the proportion of each of these forces that was effective on each of the

drivewheels. From Fig. 1A it may be seen that the force acting vertically on the drivewheels due to the pull may be considered as concentrated at P, which is the extension of the true line of draft through the tractor. This is 17 in above the ground. It is estimated that the force on the rear wheels due to the weight of the tractor may be considered as concentrated at S which is 34 in above the ground. The center of gravity of the driver is about 56-in above ground.

The tread of the tractor is 51 in and assuming a furrow 6 in deep, it was found that these forces were distributed on the land and furrow wheels as follows:

| Pounds | Total | On land wheel | On furrow wheel |
|---|---|---|---|
| Due to driver | 203 | 74 | 129 |
| Weight of tractor | 2918 | 1230 | 1688 |
| Due to pull | 533 | 254 | 299 |
| Total | 3674 | 1558 | 2116 |

When additional weights were added these were fastened to the center of the wheel, and it was assumed that these weights were effective only on the particular wheel to which each was added.

The dependability of this method of determining slippage is, of course, dependent upon the supposition that the tractor tire will react in the same way in the field when at work under a given weight as it does in the testing machine in the laboratory.

*Amount of Slippage.* The per cent of slippage of the drivewheels under the various conditions of the test is shown in Fig. 2. The amount of slippage decreases as additional weight is added to the tractor. Slippage is consistently less with lower air pressure in the tires. The data appear to indicate that beyond a certain point the addition of weight to the tractor would be ineffective. This appears to be especially true for the tests with low air pressure in the tires. The question naturally arises as to the advisability of operating with relatively low tire pressures and the addition of less weight to the tractor. This apparently tends to give the desired result without making it necessary to carry the additional dead weight.

The data presented in Fig. 2 represent the averages of land wheel and furrow wheel for each test. It was found that the slippage of the land wheel under conditions of the test was consistently higher than that of the furrow wheel. The relative difference remained about the same for various weights of the tractor. The average of all of the tests with the same tractor weight showed that the slippage of the land wheel was 39 per cent greater than that of the furrow wheel when 420 lb were added to the land wheel and 280 lb to the furrow wheel. When 140 lb were added to the land wheel and no additional weight was added to the furrow wheel, the slippage of the land wheel was 0.38 per cent greater than that of the furrow wheel.

Fig. 3 shows the comparative effect of loose ground and stubble land on wheel slippage of pneumatic tractor tires. For purposes of graphical presentation the data for the 10 and 12-lb tire pressures were consolidated, and the same is true concerning the data for the 14 and 16-lb pressures. There appears to be considerably more slippage on loose ground than where the land is hard when no other factors influence. This is especially true when tire pressures are low. The difference is not so marked for the higher pressures, and it is significant that the reverse is true for the tires at the high pressures when no additional wheel weights are added to the tractor. It appears reasonable that this should be so, because the contact area on hard ground becomes relatively small when the tire is inflated to a high pressure. If the tire under these conditions can work on loose ground where it will tend to settle into the surface, more contact area will be available.

The experience obtained from these tests indicates that under favorable conditions good results may be obtained with rubber tires on tractors for plowing. While the test was in progress a shower of rain caused the surface to be rather slippery for a few hours. Under these conditions it was impossible to do any work whatever without the use of chains. Chain equipment that was available was effective. When the chains were applied, the tractor could be made to pull under any conditions that one would wish to do field work. However, these chains were heavy, and it was a rather difficult and time-consuming task to put them on and remove them.

The tractor equipped with rubber tires cannot be used without chains when the ground is wet and slippery. As soon as the ground has dried to a certain point, the traction will again be adequate. The zone defined by the conditions under which the final change takes place is very narrow. It may be possible to continue work without any appreciable interruption or annoyance under a given set of conditions, and the addition of a very small amount of moisture may make work impossible without chains.

Chain or lug equipment that is light in weight and that can quickly and easily be attached and detached appears to be a requirement for a more complete and satisfactory use of rubber tires on farm tractors.

## Idaho Drawbar Tests of Rubber Tires

(Continued from page 65)

favor of spade lug wheels for second gear operation. Here again the pneumatic tires show the larger per cent of slippage. One trial in second gear with pneumatic tires gave a maximum pull of 1,700 lb as compared to 1,800 lb for low gear with the steel wheels.

Increasing the weight on the pneumatic tires by the addition of the two 150-lb wheel weights increased the maximum drawbar pull by approximately 300 lb, the weight added. After the wheel weights were added the maximum pull on the oat stubble was 2,000 lb as compared to 1,800 lb in low gear for the spade lug wheels. In this case the per cent of slippage for the pneumatic tires was 14.8, while the tread width increased from 12 to $13\frac{1}{2}$ in. Here again the slippage for the cleated wheels was less, being only 6.6 per cent.

The greatest maximum pull with pneumatic tires was recorded when the tractor was operated on hard road and pavement. During one trial a maximum pull of 2,600 lb in second gear was recorded for the pneumatic tires when operating on concrete pavement which had a rather badly worn bitulithic top.

The data taken during this trial indicate that the pneumatic and spade lug wheels each have a particular field of application. When operating on slippery surfaces such as a grassy field or on ground soon after a rain the steel wheels will prove superior to the pneumatic wheels. On harder surfaces, such as pavement, hard roads, or fields that are dry, the pneumatic wheels show a marked superiority over cleated wheels.

GOODRICH CUSHION RUBBER TIRES BEING TESTED FOR SLIPPAGE AND MAXIMUM PULL

# Tests of Pneumatic and Cushion Rubber Tires for Tractors[1]

By A.W. Clyde[2]

AT THE PENNSYLVANIA Agricultural Experiment Station, we have done some testing of both pneumatic and cushion rubber tires during the past season.

A cross section of the cushion rubber tire is similar to an arch. It depends entirely on the elasticity of the rubber of the sidewalls as the air under the tread is under no pressure. This type of tire is being used on industrial and road equipment, but is not yet on the market for farm tractors. It is mentioned, however, as an interesting development in rubber tires.

The tires of this type used in our tests were mounted on a Deere general-purpose tractor equipped with a tank removable for weighing fuel. Revolution counters were used on both drivewheels for getting slippage data in field tests. Maximum pull and slippage at different pulls were found with a constant load dynamometer. The tractor was then tested with both steel and rubber equipment in plowing and disking.

The results were very similar to those obtained with pneumatic tires. The maximum pull on dry sod with a 3,080-lb static load on the rear axle was from 2,000 to 2,500 lb. On wet clay or wet sod this would drop as low as 1,000 lb. The cushion rubber tires plowed with $16\frac{1}{2}$ per cent less fuel and disked the freshly plowed ground with 28 per cent less fuel than regular 10-in face steel wheels with 5-in lugs. This work was mostly done in the same gear, but it was necessary to change to a lower gear part of the time with steel wheels.

The cushion tires seem to have two main advantages over pneumatic tires: First, there is no inflation to watch nor possible trouble with punctures, and, second, there is little objectionable recoil or bouncing on rough surfaces.

It has been well proved that the rubber tire is highly efficient on dry surfaces for light or medium loads. This is due to the low rolling resistance. Little power is wasted in disturbing the soil. Usually a rubber-tired tractor will roll easier on freshly plowed ground than a steel-tired one on firm ground. There has been, however, a tendency to evade one of the weak points of the rubber tire, namely, its poor traction on a slippery surface. In our locality we sometimes have heavy dews or frequent showers which make the rubber tire almost useless without some sort of help. On a slippery surface it may fail to pull two plows, where it might pull three with steel wheels. Sometimes a wet spot in the field or an upgrade may cause trouble when most of the field is fit to work.

Chains will, of course, meet these difficulties, but they seem too cumbersome to be the final remedy. Farmers will not like to put on these heavy chains any more than anyone likes to put chains on a car. If they have to be put on to get through a wet spot, they will probably stay on until all need for them is past and meanwhile most of the advantages of rubber tires will be lost.

Weight is another method for helping traction. It seems illogical, however, to go to considerable effort to make a light tractor and then add 800 lb of cast iron to get traction. Furthermore, weight is not nearly as effective on a

(Continued on page 71)

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[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers at Chicago, December 1933.

[2]Associate professor of agricultural engineering, Pennsylvania State College. Mem. A.S.A.E.

[3]AGRICULTURAL ENGINEERING, Vol. 14, No. 2, February 1933.

[4]AGRICULTURAL ENGINEERING, Vol. 14, No. 8, August 1933.

# Tractor Tests of Steel and Rubber Tires[1]

By Evan A. Hardy[2]

THE McCORMICK-DEERING 22-36 tractor with standard wheels and extension rims, equipped with three rows of 5-in spade lugs, was tested with a 10-ft International cultivator as load. The test was conducted by the Agricultural engineering department of the University of Saskatchewan.

A Schaeffer and Budenberg recording traction dynamometer was used to determine the drawbar pull of the cultivator. The slippage was determined by means of the actual distance travelled both going and coming on each round and comparing it with the calculated distance.

The rubber equipment was Firestone pneumatic tires 28x12.75 mounted on French & Hecht wheels on the rear, and 18x7.5 tires on the front. Two 150-lb weights were placed on each rear wheel to increase the weight of the rubber-equipped wheels to nearly that of the steel wheels.

The field in which the tests were made was somewhat rolling but uniform and quite typical of large areas in Saskatchewan. The soil was a chocolate loam with a clay subsoil. The soil had been one-way disked and cropped in 1932 and had been cultivated with a duck-foot cultivator two weeks before the tests. There had been very little rainfall on the soil since the previous cultivation. The shallow tillage of the land had produced a firm soil below the 2 in of very dry, dusty surface soil.

The steel equipment with the 5-in spade lugs penetrated into the firm moist soil while the rubber tires were working on a dry, loose, fine dust mulch which might be considered as a handicap for the rubber tires.

It will be noted from the test data in the accompanying table that

1 The speed with the steel equipment, because of the firm soil, was 4.1 mph (miles per hour) on high as compared with 3.52 mph with the rubber.

2 The steel wheels showed a negative slip at the rim and a positive slip at the tip of the lugs amounting to -4.48 and 12.12 per cent, respectively, as compared to 5.85 per cent slip with the rubber tires.

3 The fuel economy of the tractor was 1.6 lb of fuel per drawbar horsepower-hour with steel wheels and 1.47 lb of fuel per drawbar horsepower-hour with the rubber tires.

4 The maximum working load in intermediate gear was 2400 lb with steel wheels as compared to 2100 lb with rubber tires.

5 An air pressure of 12.5 lb was more satisfactory than 20 lb, and that probably even lower pressure should be used to obtain the most satisfactory results because no deflection was noticed at any time with the tires inflated to 12.5 lb pressure.

The following observations will be of interest:

The reduction in speed is a serious handicap to the rubber tires. Since many field operations are performed in high gear without excessive slippage, it is impossible to travel as fast with rubber tires as with the present steel wheels.

The Saskatchewan farmer hopes that the rubber equipment will provide for somewhat higher speed in order that full advantage of the rubber tires may be had. It would appear that the only way in which this might be accomplished for replacement equipment would be by the use of larger wheels and tires.

Larger wheels would be desirable also from the fact that with the present rubber equipment it is not possible to absorb the full power of the engine in high gear through tractive effort.

Larger wheels would be important since with the rubber equipment the drawbar is considerably lower than normally and the tractor is obviously low behind.

The rubber equipment showed an increased fuel economy over the steel wheels of 8.1 per cent, which is probably

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers, at Chicago, December 1933.

[2]Professor of agricultural engineering, University of Saskatchewan. Mem. A.S.A.E.

TEST DATA ON USE OF RUBBER TIRES IN SASKATCHEWAN

Tractor, McCormick-Deering 22-36. Tests conducted on farm of Charles Agar, first with standard wheel and extension rim and three rows of 5-in spade lugs. Steel wheels then replaced by Firestone pneumatic tires mounted on French & Hecht wheels, with two 150-lb weights on each wheel. Rear tires, 28x12.75

| Test No. | Type of wheel | Miles per hour | Pull, lb | Horse-power | Fuel per horse-power hour, lb | Fuel | Per cent slippage | Gear | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Steel | 4.10 | 1302.5 | 14.30 | 1.60 | Gasoline | —4.48 plus 12.12 | High | Negative slip calculated with rim of wheel (50 in) as diameter |
| 2 | Steel | 3.22 | 2000.0 | 17.20 | | Gasoline | —5.80 plus 11.81 | Int. | Positive slip calculated with tip of lug (60 in) as diameter |
| 3 | Steel | 3.20 | 2400.0 | 20.45 | | Gasoline | —4.27 plus 13.40 | Int. | |
| 4 | Rubber | 3.62 | 1450.0 | 14.00 | | Gasoline | 6.57 | High | 20 lb pressure in rear tires—slippage calculated on wheel diameter of 49 in |
| 5 | Rubber | 3.70 | 1300.0 | 12.82 | | Gasoline | 4.92 | High | 20 lb pressure in rear tires—two wheel weights on each rear wheel |
| 6 | Rubber | 3.52 | 1341.6 | 12.60 | 1.47 | Gasoline | 5.85 | High | 12.5 lb pressure in rear tires |
| 7 | Rubber | 2.73 | 2100.0 | 15.30 | | Gasoline | 16.79 | Int. | 12.5 lb pressure in rear tires |
| 8 | Rubber | 3.04 | 1600.0 | 13.00 | | Gasoline | 8.20 | Int. | 12.5 lb pressure in rear tires |
| 9 | Rubber | This test was made on hard ground against a dead load to find the point where traction ceased. Wheels began to slip when drawbar load was 4166 lb. | | | | | | | |

RUBBER-TIRE-EQUIPPED TRACTOR BEING TESTED AT THE UNIVERSITY OF SASKATCHEWAN. NOTE SMALL AMOUNT OF DUST RAISED BY RUBBER TIRES

due to some reduction in slippage and mostly to the reduction in the rolling resistance of the tractor with rubber tires.

The rubber equipment resulted in a marked improvement in operating conditions by reducing the dust. The dust with the steel wheels was so dense that normally it would be impossible to continue, since the wheel mark of the cultivator, which was being used as a guide, was invisible most of the time. The dust with the rubber equipment was not at all objectionable.

The quality of tillage was materially improved with the rubber equipment. The wheel marks were quite in evidence after the cultivator with the steel wheels, while no marks could be seen in the soil after the cultivator with the rubber tires.

# Tests of Pneumatic and Cushion Rubber Tires

(Continued from page 69)

slippery surface as on a dry surface. On dry sod the coefficient of friction may be approximately 0.7, a weight of 3,000 lb on the axle giving about 2,100 lb tractive pull. On wet sod, if the pull drops to 1,000 lb, the coefficient of friction is about 0.33, and to bring the pull back up to 2,000 lb would require about 3,000 lb additional weight on the axle, an unthinkable amount.

Since weight seems out of the question for helping traction on slippery surfaces, and since chains are very cumbersome, I wonder if there is not an opportunity to develop some sort of lug that can be easily thrown out or withdrawn as desired. Many such devices were patented years ago for steel wheels but never got into production. Possibly changes in the treads or tires themselves may improve them greatly. At least I feel that all concerned should be looking for ways of improving the present performance of rubber tires on slippery ground.

There is now a mass of material showing fuel used and speed for tractors doing various work with rubber and steel equipment. It should be observed, however, that this material has little quantitive value because it includes the efficiencies of both the engine and the wheels. The gear ratio used and the load factor of the engine have been largely accidental and may cause considerable error, if one attributes all differences to the wheels. It seems to me that future tests should be by the more exact method wherein the power applied to the wheel and the power delivered to the drawbar are measured. These results with the travel reduction or slippage give exact information about the wheel performance. Two experiment stations have already worked in this direction. Iowa measures the torque on the rear axle[3], and Nebraska has used inlet manifold vacuum as a measure of power applied to the transmission[4]. The torque method requires the greater investment in apparatus, while the inlet manifold vacuum method may not be as exact as desired. At least the calibration of the engine should be checked often and all data be corrected for temperature and barometer. One of our mechanical engineers suggests that the fuel consumption during a certain time might be a better index of power developed than manifold vacuum. There would be the same need for frequent checking, but corrections for temperature and barometer would not be needed. I feel strongly that some method of measuring power input to the wheel is necessary to good research on wheels. Otherwise, we will have the confusing variable of engine efficiency mixed with the results. Accuracy is also important because when dealing with the difference between the input and output any error in either figure becomes a bigger percentage of error in the difference. When the true performance of a wheel is known, it will then be possible to design a tractor of right weight, power, and gear ratios to make best use of a particular wheel.

Future tests might also include extension rims for steel wheels and wheels of large diameter. So far most tests have compared rubber with single steel wheels of most common diameter. Extension rims have definite usefulness and should not be neglected. There is also evidence that large diameter wheels are superior in some ways to smaller wheels.

The foregoing points have been presented, because I believe they have not received as much attention as the advantages of rubber tires. I recognize several distinct advantages and possibilities in rubber tires for making the tractor a more general-purpose machine. No doubt the future will see some changes in tractors, so that they can take better advantage of the good features of rubber tires.

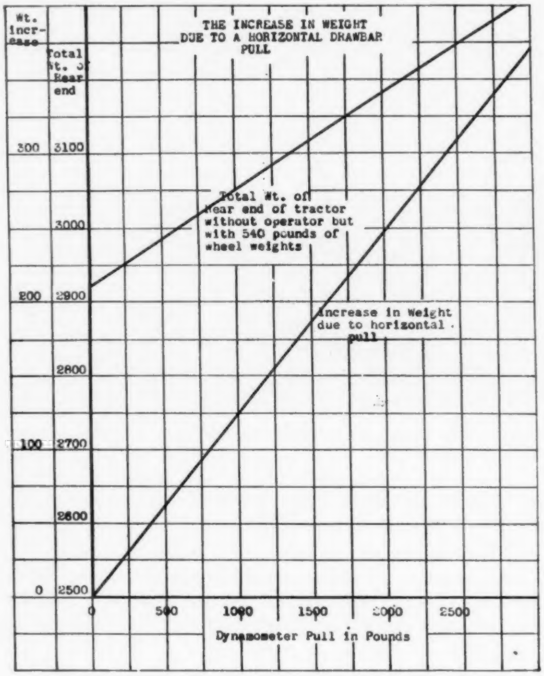



FIG. 1 THE INCREASE IN WEIGHT DUE TO A HORIZONTAL DRAWBAR PULL

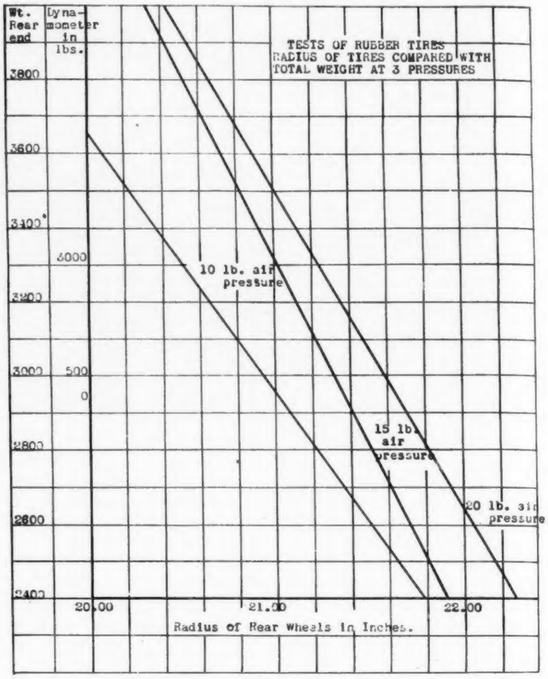



FIG. 2 RADIUS OF TIRES COMPARED WITH TOTAL WEIGHT AT THREE PRESSURES

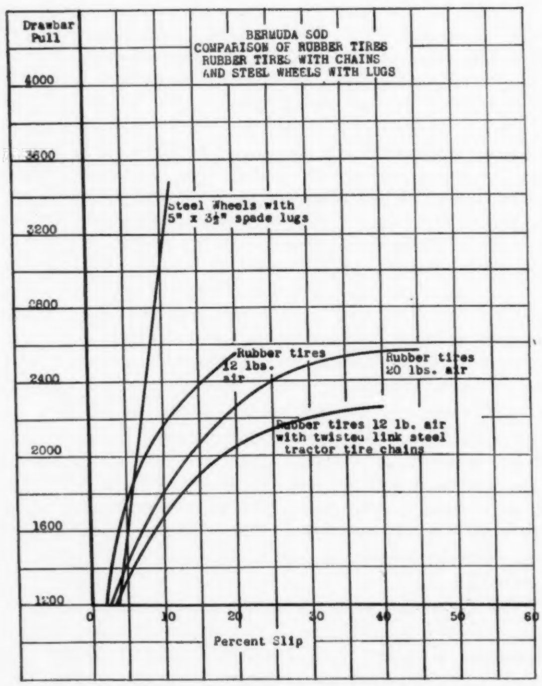



FIG. 3 COMPARISON OF RUBBER TIRES, RUBBER TIRES WITH CHAINS, AND STEEL WHEELS WITH LUGS, ON BERMUDA SOD

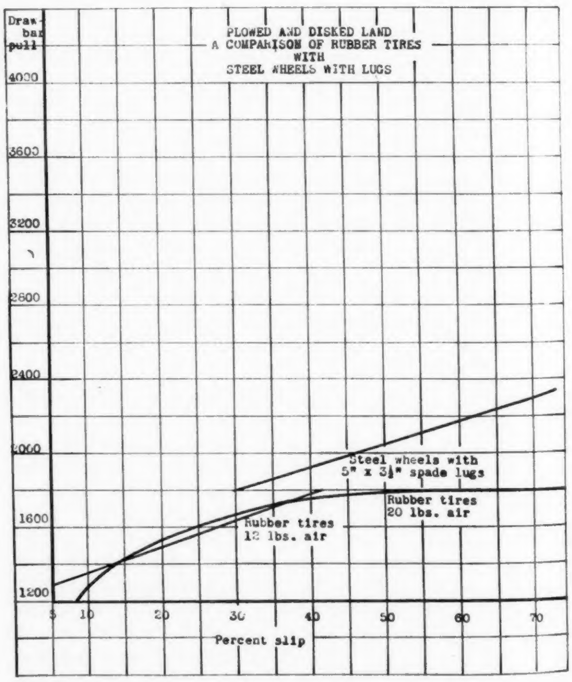



FIG. 4 A COMPARISON OF RUBBER TIRES WITH STEEL WHEELS EQUIPPED WITH LUGS, ON PLOWED AND DISKED LAND

# Tests in Texas of Pneumatic Tractor Tires[1]

By F. R. Jones[2]

THE PRINCIPAL OBJECT of these tests was to compare the traction provided by pneumatic tractor tires and steel wheels with spade lugs on sod and on a loose soil surface such as plowed and disked land.

The tractor used was a Model U Allis-Chalmers. The pneumatic tires were Goodyears—6.50x16 for the front wheels and 11.25x24 for the rear wheels. The chains for these tires were Cleveland twisted-link steel chains. For the steel wheel equipment, 28-in diameter front wheels, with a rim width of 6 in and skid rings 1½ in high, were used. The rear wheels were 42 in in diameter, with a rim width of 11 in. Spade lugs 5 in high and 3½ in wide per wheel were used.

Tests were made to obtain the per cent slip for various drawbar pulls and for various air pressures. The flattening of the rubber tires, from increase in weight due to drawbar pull, was measured. The increase in weight on the rear wheels was also measured at the same time and place as the change in radius of the tires. Such factors as actual speed of travel, fuel consumption, and power developed were not noted. The rolling resistance of the tractor was noted, and the resistance of the rubber equipment was about half that of the steel wheels on both the sod and the plowed ground.

On the Bermuda sod the pulling resistance was about 300 lb, while on the plowed ground it was about 375 lb. On the same sod the rolling resistance of the steel equipment was about 600 lb, while on the plowed and disked ground it was 725 lb. This difference in rolling resistance thus greatly favors the rubber equipment. Thus, if travelling at the same speed and pulling the same load, the power consumed in overcoming rolling resistance would be about twice as much for steel equipment as for the rubber tire equipment.

The general observations and conclusions are as follows:

1 Steel wheels and spade lugs gave a greater maximum drawbar pull than pneumatic tires on both sod and plowed ground.

2 The steel wheel has a change in radius with increased drawbar pull, but no attempt was made to measure the change.

3 If the radius of the steel wheel is considered to be constant and the change in radius of the rubber-tired wheel taken into account (by using the graphs showns in Figs. 1 and 2) ; the steel wheels and the rubber-tired equipment gave approximately the same per cent slippage from 1200 to 1800 lb when on Bermuda sod, as shown in Fig. 3.

4 The change in the corrected slippage from the slippage obtained from the observed data was in no case more than 1.9 per cent slippage. This was when there was an observed slippage of 48.3 per cent, thus making an approximate error of only 4 per cent of the actual slippage.

5 On Bermuda sod the 12 lb air pressure gave considerably better traction than the 20 lb air pressure as shown in Fig. 3.

6 The tractor pulled more and gave less slippage on Bermuda sod with both types of wheel equipment.

7 On rough sod there was considerable bouncing on the rubber-equipped tractor which tended to increase the slippage.

8 The use of chains on Bermuda sod did not seem to produce any appreciable improvement in the traction. This was probably due to the fact that the chains had a tendency to keep the tires from making proper contact with the ground.

9 On the plowed ground there was very little difference as to the slippage and the load as far as the change in air pressure was concerned, as shown in Fig. 4.

10 The tires although they were slipped considerably on sand and gravel, did not show an appreciable amount of wear as far as observation was concerned.

11 Small changes of moisture content of the top layer of the soil makes more difference in the slippage of a rubber-equipped tractor than the steel wheel tractor.

12 The tests indicated that when pulling the same load at different speeds, there was an increased slippage with increased speed. Whether there is a definite ratio or not is still uncertain from the results so far obtained.

13 It was noted that to start a load there was more slippage than after the load was started.

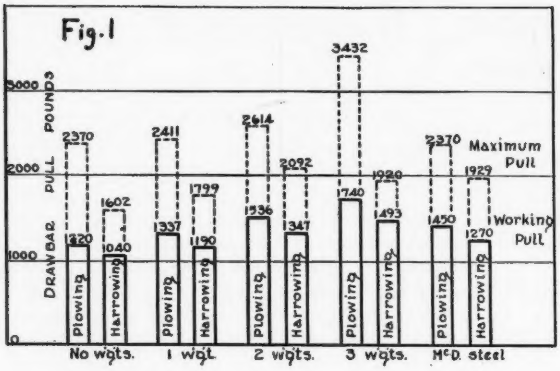
14 On most surfaces a lower inflation pressure permits the tire to flatten somewhat and secure better traction.

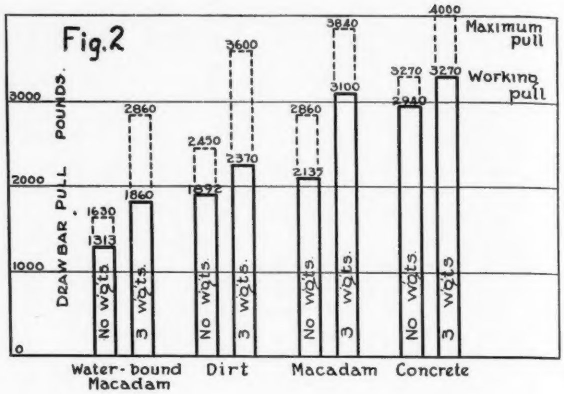
15 Since the pull per plow bottom as reported from various sources indicates that each bottom requires 600 to 1000 lb draft, and since the tractor is essentially a two to three-bottom tractor, there would be little difference in wheel slippage with a two-bottom plow if pulled at the same speed and under similar conditions.

[1]Paper presented at a meeting of the Power and Machinery Division of the American Society of Agricultural Engineers, at Chicago, December 1933.

[2]Associate professor of agricultural engineering, A. and M. College of Texas. Mem. A.S.A.E.

IN ADDITION TO THE STATE COLLEGE AGRICULTURAL ENGINEERS, THE DEVELOPMENT ENGINEERS OF FARM EQUIPMENT COMPANIES ARE STUDYING INTENSIVELY THE POSSIBILITIES OF RUBBER TIRES FOR TRACTORS AND OTHER EQUIPMENT




# Field Tests of Air Wheels for Tractors[1]

By F. L. Fairbanks[2]

THE EQUIPMENT USED in the tests (season of 1933) reported herein consisted of a McCormick-Deering 10-20 and a Farmall F-12 tractor. Firestone 11.25x24 and Goodyear 11.25x24 and 9x36 pneumatic tires and steel wheels constituted the wheel equipment for making the tests. A Liberty truck weighing 10,800 lb furnished the load for the road test. For the field tests a single-bottom, 16-in plow and a two-bottom 14-in plow and spring-tooth harrows were used.

The plowing and harrowing were done in the same field for both summer and fall work. The field was covered with a light sod, and there was a uniform, gentle slope to the south. Runs were made in both directions up and down the slope. The soil was Canfield silt loam.

The road tests were made on firm dirt, water-bound macadam, macadam, and concrete, all in dry condition.

The test runs with rubber tires for summer and fall plowing and harrowing were made with no weights, and with one, two, and three weights in each drivewheel. Fig. 1 shows the drawbar pull in each case, and also for the steel wheels, the tractor used being the McCormick-Deering 10-20, and the rubber tires 11:25x24.

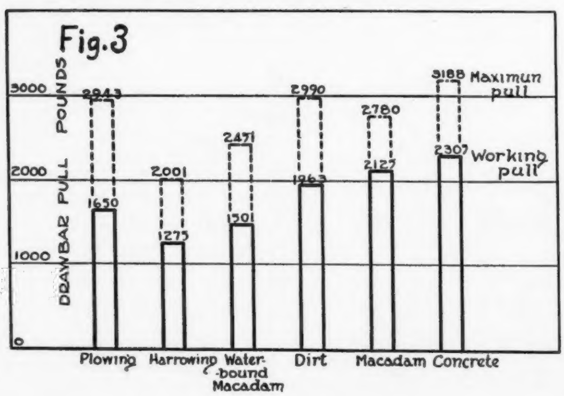
The road tests were made on four types of road surface with no weights, and with one, two, and three weights in each drivewheel. Fig. 2 shows drawbar pull in these tests with the McCormick-Deering tractor equipped with 11.25x 24 tires.

Fig. 3 gives a summary of the drawbar pull data from these tests for the Farmall F-12 tractor equipped with 9x36 tires.

All runs were made to measure the working pull, that is, at normal full load, and the maximum pull, which of course would be accompanied by excessive slip of the drivewheels, or a reduction in engine speed, but under conditions in which the tractor would still move forward.

[1]Progress report on Agricultural Engineering Research Project IV "Farm Power Machinery" at New York State College of Agriculture. Cooperators: Department of Farm Practice, Department of Animal Husbandry, International Harvester Co., Firestone Tire & Rubber Co., and Goodyear Tire & Rubber Co.

[2]Agricultural engineer, Cornell University. Mem. A.S.A.E.




## Rubber Tires and Speed

FOR NEARLY a century after invention of the reaper and the steel plow, speed as a factor in design and operation of field machinery remained almost a constant, established by the gait of the horse. In the latter part of the century, to be sure, came the tractor and a fractional increase in field speeds. Not only did traction efficiency fall off prohibitively with increased speed, but among the basic implements of tillage there were no designs capable of efficient work at higher speeds. Created as they were by a century of empirical development, there could be expected no sudden adaptation to materially higher speeds.

With its amoeboid manner of soil contact the pneumatic tire has reduced soil disturbance to a minimum and made tractive efficiency largely independent of speed. It promises to change field speed from a constant to a wide variable. In effect it introduces another dimension into the calculations of the designer, especially he who deals with soil-working members.

Rubber traction may reopen the whole question of weight-to-pull relationship in the tractor, but it seems likely that power, being proportional to speed, will be demanded in far greater measure than weight, placing emphasis on engines of high specific power, and on weight-saving construction throughout the tractor. Certainly in drawn machines lightness will be at a premium, while the dynamic stresses implied by speed will demand higher elastic limits and ultimate strengths.

# Agricultural Engineering Digest

A review of current literature by R. W. TRULLINGER, senior agricultural engineer, Office of Experiment Stations, U. S. Department of Agriculture.

THE RATING AND USE OF CURRENT METERS, *C. Rohwer*. Colorado Sta. Tech. Bul. 3 (1933), pp. 133, figs. 88. The investigations reported in this bulletin were conducted cooperatively by the station and the U.S.D.A. Bureau of Agricultural Engineering.

The investigations were divided into two parts. The first was devoted to the study of the action of the different types of current meters when rated under various conditions, and the second to the comparison of the discharge determined by different kinds of current meters under various conditions, using different methods of measurement and that from a standard Francis weir.

In order to check the operation and characteristics of the cup and propeller meters under various conditions, representative meters of the different types were rated at both the tangent and rotary stations at the hydraulic laboratory at Fort Collins, Colo. The tests were conducted for the most part on the different models of the Price cup meters and the Ott propeller meters, but tests were made also on the Fteley-Stearns, Ritchie-Haskell, and Hoff meters. In addition, the rotary and tangent-station ratings were compared by making ratings at both stations on the same meter under similar conditions.

The tangent rating station consisted of a concrete-lined channel 210 ft long, 5 ft wide, and 3.5 ft deep, a variable speed electrically driven rating car, a clock having a seconds pendulum, and an electric recorder for registering the time, the distance, and the meter revolutions.

The consistency with which the plotted points fall on the curves of typical ratings of the principal kinds of current meters made under similar conditions at the tangent rating station is taken to indicate that it is possible to get accurate results with the rating equipment.

Replicate ratings of Price meters made under identical conditions, except that the meters were removed from the car and reset between ratings, gave almost identical results for velocities greater than 1-ft per second, but showed considerable variation at lower velocities. Ratings of three Price cup meters, one Ott propeller meter, and one Hoff propeller meter at different depths showed that the depth at which the ratings were made had very little effect on the results except in the case of the cup meters. Under these conditions the cup meters showed some changes, and when at the water surface the changes were so erratic as to make the ratings unreliable. The Hoff meter only of the propeller meters was rated near the surface and it showed no effect when rated in this position. Nearness to the walls of the channel had little effect on the ratings except in the case of the cup meters. The Price meters ran more slowly than normally, in general, when the rotating force was acting on the cups away from the wall. Integrating the meters while making ratings reduced the speed of rotation of the Price meters but had very little effect on the Ott meters.

Tests made on two Price meters, three Ott meters, one Fteley-Stearns meter, one Ritchie-Haskell meter, and one Hoff meter to determine the effect of oblique currents in the horizontal plane on these meters showed that all the meters run more slowly when subjected to oblique currents and the amount of retardation varies with the angle of obliquity and also with the side from which the the current comes. The tests also show that the cup meters overregister and the propeller meters underregister in resolving horizontal oblique currents into their axial components. The cup meters overregister less than the propeller meters underregister.

Tests on Price, Ott, Ritchie-Haskell, and Fteley Stearns meters to determine how closely these meters resolve oblique velocities in the vertical plane into their axial components showed that the propeller meters measure the axial components of vertically oblique currents more accurately than the cup meters, and that the cup meters are more accurate when the current comes from above, whereas the propeller meters are more accurate when the current comes from below. Tilting the cup meters to the right and left had little effect except at velocities less than 2.5 ft per second.

Tests on a Price meter to determine the effect of bending the cups, of coating the cups with oil, of covering the cups with a coating of sand and shellac, and of weighting one of the cups, showed that bending the cups had a marked effect on the rating and that sanding the cups reduced the number of revolutions of meter slightly, but that covering the cups with oil or weighting one of the cups had little if any effect on the rating. The effect of guys on a Price meter to hold it rigidly in place was to cause the meter to rotate more slowly, and the greatest effect was produced by guys of largest diameter. Guys attached near the top of the meter yoke had a greater effect than those attached 3 in above it, and the effect of the latter was small. Ratings of a Price meter when held by rods of different diameters showed that the revolutions of the meter decreased as the diameter of the rod increased.

Observations on a Price meter and an Ott meter to determine the effect of making ratings in flowing water showed that for velocities greater than 1 ft per second there is no effect on the ratings.

A comparison of the ratings of a Price cup meter, an Ott propeller meter, and a Hoff propeller meter, when supported by rods and cables, showed that in general the meters run more slowly when rated as cable meters and that having weights above and below and meters retards them more than single weights, but single weights above the meters make them revolve more rapidly than when the weights are at the bottom. These tests showed also that the Ott meter operated more consistently when rated as a cable meter than either the Hoff or the Price meter.

Observations on the effect of the length of cable on the rating of a Price meter, a Hoff meter, and an Ott meter showed that in general the Price and Ott meters run slower as the length of the cable increases, whereas the Hoff meter runs faster. The difference in length of the cable causes an appreciable difference in the rating of the Hoff meter. Comparison of the cable ratings of a Price meter when using one and two standard weights, both below the meter, showed that the two weights make the meter run more slowly than when the single weight is used.

Ratings of three Price meters and three Ott meters made at the rotary station under various conditions, for comparison with those made at the tangent station, showed that regardless of the radius of rotation the cup meters run more slowly at the rotary station than at the tangent station. This is also true of the propeller meters with the exception of an Ott, which, under certain conditions, runs faster when rated at the rotary station than when rated at the tangent station, but the difference is small.

As the radius of rotation decreased, two Price meters ran more slowly, whereas one Price meter and two Ott meters ran faster. One Ott meter was apparently not affected by the radius of rotation. The cup meters ran more slowly at the rotary station than at the tangent station, regardless of whether the rotating force was acting on the inside or the outside cups.

The ratings made with and without tails at the rotary station on a Price meter and two Ott meters showed that the Price meter runs faster without than with the tail, regardless of the direction of rotation of the meter, and that the Ott meters under some conditions run faster and under others slower when operated without the tail, whereas the ratings made at the tangent station showed that the tails have little if any effect on the ratings.

The tests also showed that the addition of guy wires to hold the meters more rigidly did not make the rotary- and tangent-station ratings of the meters agree.

Ratings of two Price meters at the rotary station at a constant radius, but at different depths, showed that the revolutions of the meters increased as the depth increased, up to a depth of 2 ft, and that from there on the revolutions decreased for the most part, but with the exception of the rating of one Price meter at the 2-ft depth, the meters run slower at the rotary station than at the tangent station.

Observations at the rotary station on two Price meters when held rigidly by the supporting rod and when free to turn in a horizontal plane showed that in general the meters run faster when free to turn, and that when the rotating force is acting on the outside cups and the meters are free to turn in a horizontal plane the meters run at about the same speed at the rotary station as they do at the tangent station.

The tests made on a Price meter, to find out how much the theoretical radius of rotation had to be increased to make the rotary and tangent ratings coincide, indicated that, if when the rotating

(Continued on page 78)

# AGRICULTURAL ENGINEERING

Established 1920

A journal devoted to the advancement of the theory and practice of engineering as applied to agriculture and of the allied arts and sciences. Published monthly by the American Society of Agricultural Engineers, under the direction of the Publications Committee.

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RAYMOND OLNEY, Editor

R. A. PALMER, Associate Editor


## Rubber Tires for Free-Wheeling Uses

DESPITE THE WAY that the rubber tire for farm tractors has claimed the limelight of engineering and popular attention, it appears now that the rubber tire in non-tractive farm applications has given even better account of itself. Under combines and corn pickers, in fields of varying softness and on wagons and trailers under all manner of farm and road conditions, the low-pressure tire has shown such efficiency in draft reduction and shock elimination as to merit as much attention and more enthusiasm than the tractor driving tire.

In these non-tractive applications the rubber tire retains all of its easy-rolling virtues, with no offsetting fault of low tractive capacity. In consequence it has almost no limitations arising from soil or soil condition. It does have serious economic limitation if it is to be used on a single implement or machine, for many farm devices are used for but a few days or at most a few weeks annually, and the investment charge may rule out the rubber tire.

Since most farm machines are used successfully rather than simultaneously, and the number which can possibly be used at one time is limited by the tractor or other power units available, a small number of rubber tires might serve a whole list of equipment if they were easily and quickly interchangeable. As change-over tires for present designs of implements, the number of sizes required would be prohibitive. But if a graded series of a few sizes were worked out, it should be possible to design new equipment (as it is brought out from time to time) to take some one of the standard tire and wheel sizes.

In such a development, the tire and wheel should be a unit. If the land wheel of a plow took the same size as the front wheel of a combine, the wheel would be needlessly strong for the plow. Yet, with low rolling resistance, the excess weight would be no great objection. And attention may well be given toward carrying the demountable wheel even further than in automotive practice.

If wheels and tires are used progressively on sundry machines, and the bearings are so used also, the annual usage will justify the general use of appropriate antifriction bearings. Instead of demounting the wheel at the hub, it should be possible to mount the bearings on a sleeve slipped over what may be a rough axle, the entire assembly removable by taking off an axle nut. In this way the adjustment and lubricant of the bearing could be preserved, and the everpresent dirt excluded. The change should be within the mental compass of anyone qualified to grease a wagon.

As long as open-air storage of farm equipment remains rather general, removal of tire and bearings, either to an active machine or to shelter, would protect two of the more expensive and more perishable elements from weather-damage. Weather, be it noted, is to be counted a cost factor for rubber tires, whether it appears as housing for protection or as depreciation for lack of housing during periods of disuse.

Considering both the number of tires involved per farm and the limitations of adaptation as they now appear, there may be a larger market for rubber tires on wagons, implements, field machines, and the front wheels of tractors than there is as tractor driving members.

## Awaiting the Tractor Designed for Rubber Tires

THUS FAR we have been fitting rubber tires to tractors. We have yet to see a tractor fitted to rubber tires. Until that is done the rubber-tired tractor will not develop its full efficiency, nor can we predict with any accuracy what performance may be expected when the entire unit is engineered from the start on a rubber-tire basis. Presumably the striking efficiencies already achieved will be made somewhat greater. More important, it is to be hoped that the limits of traction, which now restrict the adaptability of the rubber-tired tractor, will be materially broadened.

The tire and wheel manufacturers have done a commendable and commercially practical job of developing and standardizing a few sizes of tire with which nearly all current-model tractors may be equipped. These standards should be regarded as temporary makeshifts, designed to squeeze in a rubber tire where a steel rim was intended to be, with not too punctilious a regard for tread width or torque ratio. Proper weight and its distribution have recognition in the dubious form of wheel weights.

But before these makeshift tire standards are discarded or augmented, and preferably before any real rubber-tired tractors are put into production, there might well be some studies—something approaching pure research—of the soft rubber tire as a traction device. Such studies should develop data on the tire itself, and on its relationships with sundry types and conditions of soil, wholly apart from complicating factors arising from the characteristics of the unit on which it is used, particularly the characteristics of tractors which were designed with no thought of rubber tires.

If there is an optimum relation between section and outside diameter, it should be determined, with variations according to governing circumstances of soil, loading, etc. There probably is room for more knowledge on inflation

pressures and contact areas in relation to soil, load, and draft. There may be something to learn about tread patterns and possibly of tread materials. Some of these and other problems may be strictly the job of the tire engineer, but there will be room for much profitable cooperation between him and the agricultural engineer.

It would appear that the federal farm tillage machinery laboratory at Auburn, Alabama, announced in these pages last month by R. B. Gray, chief of the division of mechanical equipment, Bureau of Agricultural Engineering, U. S. Department of Agriculture, will be a logical place for such studies. The soil bins will afford a useful, if not complete, assortment of soil types. There will be facilities for unusually accurate control of its condition. The mechanical equipment seems ample and appropriate for just such investigation.

Probably no other single task which might be assigned this laboratory would have so much immediate economic significance to American agriculture. Probably no other project would be so promptly and largely reflected into industrial activity and employment, if we may assume that the findings of such research pave the way for the true rubber-tired tractor.

In any case it is about time to stop observing the overall performance of a steel-wheel tractor fitted with makeshift tires, and begin to correlate the tire performance with energy input to the tire itself, with the weight it bears and the draft it develops, all in relation to the soil. It would be helpful, too, to have a standard procedure for determining and defining soil condition with respect to the factors significant in rubber-tire performance.

Once the characteristics of the rubber tire are established, and its most favorable working conditions known, the tractor designer will create a rubber-tired tractor.

# NEWS

## Southern Agricultural Engineers Meet

THE SOUTHERN SECTION of the American Society of Agricultural Engineers held its yearly meeting, as usual, with the Association of Southern Agricultural Workers, at Memphis, Tennessee, January 31, and February 1 and 2, the sessions being held only on the afternoons of those days.

The first session on January 31 opened with an address by Arthur Huntington, President of the Society. This was followed by a paper on the influence of farm machinery on the intelligence and living standards of farmers by W. C. Ayres, director, Delta Experiment Station; a paper on how the plow works by M. L. Nichols, agricultural engineer, Alabama Polytechnic Institute, and a paper on the status of the plow problem by I. F. Reed, agricultural engineer, U.S.D.A. Bureau of Agricultural Engineering.

On the second day the entire session, except for a business meeting, was devoted to the subject of soil erosion and its control as handled by the CCC. The discussion was led by W. B. Allison, drainage engineer, U.S.D.A. Bureau of Agricultural Engineering, and participated in by his assistants.

On the third afternoon, T. N. Jones, agricultural engineer, Mississippi State College, presented a paper on methods of curing hay as influenced by plant physiological reactions. A paper on soil crusts and methods of overcoming them was presented by A. Carne, agricultural engineer, Alabama Polytechnic Institute. E. L. Stedronsky, junior agricultural engineer, U.S.D.A. Bureau of Agricultural Engineering, presented a paper on the power requirements in cotton ginning.

Another feature of the three-day program was the paper on rural electrification in the South, presented by Mr. G. M. Rommel, agricultural engineer, Tennessee Valley Authority.

Officers of the section elected for the ensuing years were as follows: Chairman, J. T. Copeland, extension agricultural engineer, Mississippi State College; first vice-chairman, G. I. Johnson, agricultural engineer, University of Georgia; second vice-chairman, D. S. Weaver, agricultural engineer, North Carolina State College; and secretary, J. B. Wilson, extension agricultural engineer, Alabama Polytechnic Institute.

## Personals

*Ray W. Carpenter* and *C. E. Wise, Jr.*, agricultural engineers, University of Maryland, are joint authors of Circular No. 102 recently issued by the extension service of that institution. The title of this circular is "How to Calculate Field Areas."

*H. L. Garver*, investigator, and *L. J.* Smith, secretary, Washington Committee on the Relation of Electricity to Agriculture, are joint authors of the ninth annual progress report of investigations of the various uses of electricity for agriculture in the state of Washington, recently issued by that Committee. The report is available in mimeographed form.

*E. W. Lehmann*, professor and head of the department of agricultural engineering, University of Illinois, is the author of an article, entitled "The Relation of Engineering to Agriculture," which appeared in the December 1933 issue of "The Technograph," published by the students of the college of engineering at the University of Illinois.

*C. A. Logan*, agricultural engineer, Kansas State College, is one of the authors of a mimeographed report, entitled "Electric Brooders," based on a cooperative project (No. 83) of the departments of poultry husbandry and agricultural engineering of that institution. It is designated as Contribution No. 66 of the Department of Agricultural Engineering.

*Howard Matson*, agricultural engineer, University of Kentucky, is the author of Circular No. 226, entitled "House Storage Structures and Equipment," recently issued by the agricultural extension division of that institution.

## New ASAE Members

*Alfons Alven*, Chicago manager, Bearings Company of America, 205 W. Wacker Drive, Chicago, Ill.

*George W. Curtis*, district manager of sales, Timken Roller Bearing Company, 715 N. Van Buren St., Milwaukee, Wis.

*Gerald E. Ryerson*, agricultural engineer, Soil Erosion Service, U. S. Department of the Interior. (Mail) Federal Building, LaCrosse, Wis.

## Applicants for Membership

*H. W. Gerlach*, superintendent, flood and erosion district, Wauzeka, Wis.

*G. B. Hanson*, engineer, Wisconsin Conservation Commission, State Capitol, Madison. (Mail) 515 North Henry St.

*Arthur C. Jacquot*, instructor, agricultural engineering department, Washington State College, Pullman, Wash.

*Willard L. McFillan*, engineering foreman, U. S. Forest Service, Camp Kenney, Kalvesta, Kans.

*Earl C. Rieger*, assistant to chief engineer, gas power laboratory, International Harvester Company, 2626 W. 31st Blvd., Chicago, Ill.

*Colin A. Taylor*, assistant irrigation engineer, Division of Irrigation, Bureau of Agriculture. (Mail) Room 4 Post Office Building, Pomona, Calif.

# Agricultural Engineering Digest

(Continued from page 75)

force is acting on the inside cups, the meter is set on a radius about 1 per cent greater than that used in computing the velocity, the ratings will agree.

The ratings of the current meters used in making the comparisons between the weir and the current-meter measurements showed that, although the equations of the ratings made at different times differ slightly there are compensating factors in the equation which make the velocities computed from the equations of ratings agree quite closely with each other.

The tests to determine the accuracy of current-meter measurements in shallow flumes showed that both cup and propeller meters are inaccurate under this condition and that the errors increase, in general, as the depth decreases.

The Price cup meter gave the best results when the vertical-integration method was used, but the Ott and the Hoff propeller meters were most accurate when the measurements were made by the 2-and-8-tenths method.

In view of the fact that the errors in the measurements with each meter and by each method are quite consistently too large or too small. It seems obvious that the accuracy of the measurements in shallow water could be materially increased by applying the correction derived from these tests for the meter and the method.

The results of a series of current-meter measurements made in the converging section of Parshall measuring flumes indicated that more accurate current-meter measurements might be made if the gagings were made in structures with converging rather than parallel walls.

WHAT DETERMINES THE LENGTH OF LIFE OF PREPARED ROLL ROOFINGS? *H. Giese, H. J. Barre,* and *J. B. Davidson.* Iowa Sta. Bul. 304 (1933), pp. 25-39, figs. 9. This is a brief account of an investigation to determine the quality factors of three-ply prepared roll roofing, a more detailed account of which was presented in Bulletin 109 of the station.

AGRICULTURAL ENGINEERING INVESTIGATIONS AT THE IDAHO STATION. Idaho Sta. Bul. 197 (1933), pp. 20-24, 54, 55. The progress results of investigations on reclamation, irrigation, drainage, farm power and machinery, rural electrification, farm buildings and equipment, utilization of surplus and waste products, and harvesting hay are briefly presented.

FARM BUILDING PLANS, *J. C. Wooley* and *R. W. Oberlin.* Missouri Agr. Col. Ext. Circ. 305 (1933), pp. 20, figs. 26. Working drawings for several different types of farm buildings are presented.

IRRIGATION WITH ALKALI WATER [trans. title], *P. Bignami.* Agr. Colon. [Italy], 26 (1932), No. 12, pp. 585-589. A brief summary is given of work by others on the use of alkali water for the irrigation of vegetable and field crops in particular, indicating the tolerances of different crops to sodium chloride.

FITTING THE MECHANICAL REFRIGERATOR INTO THE HOME, *E. B. Lewis* and *M. P. Brunig.* Nebraska Sta. Circ. 45 (1933), pp. 11, figs. 7. The purpose of this publication is to point out some of the conditions under which the refrigerator has been expected to operate successfully and some of the effects of these conditions upon the operation of the machine. The effects on operation were studied in homes and in the laboratory where duplications of proposed settings were reproduced.

It was found that the operating characteristics of the mechanical refrigerator are often disregarded when refrigerators are placed in alcoves. From 35 to 50 per cent increased operating costs may be incurred by faulty enclosures. Where the compressor unit is on top of the cabinet the alcove ceiling should be 12-in or more above the coils. Where the compressor unit is enclosed within the cabinet and receives ventilation either through the back or sides of the cabinet a 3-in space must be provided at the back or sides in addition to the top space. Where curtains, grills, or other objects prevent sufficient circulation of air over the top, a special air shaft may be installed.

UTENSILS FOR THE ELECTRIC RANGE, *E. H. Roberts.* Washington Col. Sta. Bul. 283 (1933), pp. 20, figs. 2. This bulletin reports investigation the purpose of which was to determine by means of standardized tests which pans are the most efficient for use in top stove and oven cookery.

Numerous experiments were made to determine the speed and thermal efficiency of top stove and oven utensils for use with the electric range. It was found that the most efficient top stove utensil has a dull, flat bottom, high polished sides, a well-fitting cover, and is made of material heavy enough to insure durability. The most efficient oven utensil is made of a material which readily absorbs or transmits radiant heat.

SOLUBILITY OF ETHYL ALCOHOL IN GASOLINE, *O. C. Bridgeman* and *D. Querfeld.* Indus. and Engin. Chem., 25 (1933), No. 5, pp. 523-525, figs. 5. Studies conducted at the U. S. Department of Commerce Bureau of Standards on the solubility of ethyl alcohol containing various percentages of water in a number of gasolines are reported. The procedure used consisted in preparing quantitatively solutions of ethyl alcohol, of known water content, in gasoline (warming if necessary) and in measuring the critical solution temperature by noting the appearance of a second phase on cooling.

Data were obtained on 23 gasolines. In every case critical solution temperatures were measured on blends with aqueous ethyl alcohol solutions containing approximately from 99 to 93 per cent of alcohol by volume.

It was found that the critical solution temperature decreases markedly as the concentration of water in the alcohol solution decreases and as the percentage of gasoline in the blend decreases. At each constant percentage of gasoline in the blend, it was found that the logarithm of the percentage, $s$, of water present was a linear function of the reciprocal of the critical solution temperature, $T$, in absolute Centigrade degrees, so that $\log s = a + (b/T)$. For straight-run fuels of the same volatility, the critical solution temperatures differed little from fuel to fuel. For straight-run fuels of similar volatility, the source of crude from which the gasoline is distilled appeared to have a comparatively minor effect. Topping a fuel of about the volatility of U. S. motor gasoline so as to reduce the 90 per cent temperature approximately 40 deg C produced a marked lowering in critical solution temperature. Increase of the volatility at the lower end of the distillation curve likewise produced considerable effect.

With the exception of two cracked gasolines, none of the gasolines studied would give sufficiently low critical solution temperatures to make practical the use in freezing temperatures of blended fuels containing up to 50 per cent alcohol unless the alcohol was almost entirely free from water. Under such conditions addition of other materials to increase the solubility is necessary.

ON THE THERMAL CONDUCTIVITY OF VARIOUS INSULATORS AT ROOM TEMPERATURE, *C. D. Niven.* Canad. Jour. Res., 9 (1933), No. 2, pp. 146-152, figs. 2. In a contribution from the National Research Laboratories at Ottawa, Canada, the values for thermal conductivity of various common materials chiefly used in the walls of houses are given. By plotting the results obtained, as well as those obtained by other experimenters, on a density-conductivity diagram there is a general indication that at higher densities thermal conductivity increases with increase of density much more rapidly than it does at low densities.

DATA FOR DESIGN OF RETAINING WALLS, *A. H. T. Williams.* Concrete [Chicago], Cement Mill Ed., 41 (1933), No. 9, p. 10, fig. 1. These data are presented in consolidated form by means of charts, graphs, and formulas.

FARM LINE CONSTRUCTION, *M. Eldredge.* Elect. World, 102 (1933), No. 9, pp. 268-272, figs. 3. Data are presented on cost of rural line construction and on cost-saving methods. It was found that 600-ft spans on 30-ft poles with copper weld conductors can be used satisfactorily and at a saving in costs. Data are given on details of design and costs.

THE USE OF SYNTHETIC METHANOL AS A MOTOR FUEL, *D. A. Howes.* Jour. Inst. Petroleum Technol., 19 (1933), No. 114, pp. 301-331, figs. 26. The results of experiments on high-duty, single and multiple-cylinder engines using synthetic methanol as fuel are given. At compression ratios of 9.6 and 10.6, methanol gave the same advantage over ethyl alcohol in power output in a single-cylinder engine as an increase in compression ratio of one unit.

A compression ratio of 7.0 was used for the 50:50 gasoline-benzol blend and a compression ratio of 8.0 for the alcohol fuels. At the latter compression, methanol gave approximately 6 to 8 per cent greater power than the fuel which consists essentially of ethyl alcohol. Tests in a wide range of multi-cylinder engines confirmed those made in a single-cylinder engine, but exhibited other phenomena, such as the single effects of distribution and preheating of charge, etc. In the majority of engines the higher the methanol content of the fuel, the higher is the maximum power output.

Tests on a supercharged four-cylinder engine of low capacity and 5:1 compression ratio showed the large increase in power obtainable by the use of methanol as against a gasoline-benzol

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mixture. This increase in power is approximately 26.5 per cent. A 50-50 methanol-benzol mixture gives 2.5 per cent greater power than a 50-50 ethyl-alcohol-benzol mixture.

Studies on the use of methanol as a fuel when mixed with gasoline showed that the satisfactory use of methanol as a constituent of ordinary motor fuels depends upon the proper combination of cost, power output, and rate of fuel consumption. This has been simplified, since it was found that the addition of methanol to an ordinary gasoline does not increase the rate of fuel consumption at mixture strengths slightly richer than the theoretical, providing the concentration of the methanol is kept below 15 to 20 per cent by volume. Measurements of volumetric efficiency have shown quite conclusively that this is due to the higher latent heat of the methanol mixture increasing the rate of air consumption. At the methanol concentration of above 15 to 20 per cent, the loss in caloric value more than compensates for the gain in latent heat, and the rate of fuel consumption for a given power output then increases.

The addition of methanol to a mixture of gasoline and benzol containing 30 per cent of benzol resulted in a marked increase in power and this was maintained until the methanol concentration reached 20 per cent, after which the addition of more methanol caused the power output to fall and the rate of fuel consumption to rise.

The results of tests of the antiknock properties of methanol-gasoline mixtures on a variable compression engine were also given.

It was found that methanol has the advantage of having the same antiknock value (relative to benzol) at an engine jacket temperature of 150 deg C as at 100 deg. As an antiknock blending material methanol is slightly superior to ethyl alcohol and is thus the most valuable material that exists in large quantities for the improvement of the knock ratings of commercial spirits, with the exception of such dopes as tetraethyl lead.

Studies of the miscibility of methanol with other motor fuels showed that, with the exception of benzol mixtures, methanol is only soluble in market spirits to a negligible extent at —10 deg. Therefore, a blending agent is always necessary. In the case of cracked spirits, an olefin content of 20 per cent has a negligible effect on methanol solubility. Reduction in average boiling point causes a greater increase in methanol solubility than the presence of the olefins normally met with in cracked spirits.

Methanol is more soluble in a benzol mixture which contains 53 per cent of total aromatics and 30 per cent of benzol than in a spirit which contains 63.2 per cent of aromatics. Methanol has the same solubility at —10 deg in casing-head gasoline of midpoint 59-deg and 2.7 per cent aromatics as in spirit of midpoint of 112.5 deg containing 25.8 per cent aromatics. This illustrates the importance of volatility upon methanol solubility. Gasolines can be produced which are capable of dissolving quite large amounts of methanol without the addition of a blending agent.

It was found further that the solubility of methanol in any gasoline or hydrocarbon is dependent to a marked extent upon the temperature. The lower the temperature, the lower the solubility, and vice versa.

Studies of the effect of the addition of water to methanol gasoline blends showed that it is essential for a methanol blend to have a high water tolerance, i.e., its properties must be such that it will dissolve an appreciable amount of water before separation into two layers occurs. The amount of water which can be added to the mixture before separation occurs depends upon temperature, amount of methanol present in the blend, and excess of benzol present in the blend. The lower the temperature the smaller is the water tolerance of a given blend. Also the greater the excess of blending agent present the greater is the water tolerance. It was found that methanol does not absorb water as readily as ethyl alcohol.

Thermal Conductivity and Surface Treatment of Silo Walls, *H. Giese*. Iowa Sta. Bul. 303 (1933), pp. 22, figs. 14. The work reported in this bulletin deals with two problems in connection with the use of the silo. The first part relates to the thermal conductivity of the wall and its influence on the amount of frozen silage. The second part reports observations on a number of surface treatments which gave promise of rendering the wall airtight and watertight, and also of reducing the erosion of the wall due to the silage acids.

It was found that temperatures taken inside the north wall on concrete, hollow-block, and wooden-stave silos, follow outdoor temperatures rather closely and show little advantage in favor of any one material. Temperatures taken near the center of the silo are higher and fluctuate less than those near the wall surface. Under most conditions, silage itself is a good insulator. Much heat may be lost through open doors or out of the top of an unroofed silo. Exposure to cold winds is an important factor. Any of these or a cmbination of them may have more influence upon the amount of frozen silage than the construction of the wall.

All of the materials tested in connection with the study of wall surface treatments gave complete protection for a limited time only. Cement plaster gave the best protection in rendering a clay-block silo wall airtight, but considerable difficulty was experienced in securing a satisfactory bond with the tile.

Bituminous coatings proved satisfactory on tile silos and are easily applied. A high-grade roofing cement containing asbestos fibers in asphalt will stay in place better than asphalt alone. At least the first coat of this cement should be thinned with gasoline to a consistency which will permit application with a brush and so that it may be used cold. Hot applications of asphalt chill quickly upon contact with the cold silo wall, harden at once, and fail to bond.

The apparent necessity for wall treatment on concrete-stave silos has been to stop, or at least retard, the corrosive action of silage acids. Several of the materials accomplished this purpose fairly well. Difficulty was experienced with all specimens due to the scaling of the original cement wash. For this reason, if the wall has been coated with a cement wash, treatment should be deferred until all traces of the original wash are gone.

Forcing Frames and Seedbeds: Soil Heating by Means of Lead-Covered Resistance Cables, *E. A. Beavis*. Electrician [London], 110 (1933), No. 2865, pp. 552, 553, figs. 5. Experiments with a forcing frame using electricity to heat the soil are briefly reported.

The frame took the form of a brick pit 2.5 ft deep having a ground surface area of approximately 7 by 5 ft. About 20 yd of cable was used at a spacing of 7 in. There was a depth of soil of 6 in which took nearly two days to reach its final temperature, and it was found that a maximum gradient of about 10 deg F existed through this thickness of soil.

Results were obtained with runner beans, cabbage, turnips, onions, lettuce, radishes, parsnips, and beets. The growth of runner beans especially was greatly accelerated by the artificial heating.

# Literature Received

Farm Machinery, by *Archie A. Stone*, head, department of farm mechanics, New York Institute of Applied Agriculture. John Wiley and Sons, Inc., New York, 1934 (Second Edition). Cloth, 5½x8¼ in, 466 pp, 285 illus, $3.00 net. This book is one of the Wiley farm series and this edition has been revised and corrected and new material added. It is designed to meet the special need, under present conditions, in connection with the repair and reconditioning of farm implements. In its preparation careful thought has been given to the needs of pupils preparing for specific farming operations. The problem attitude has been maintained throughout. The "shop jobs" and "laboratory studies" are organized so as to stimulate interest in the active study of machinery problems and to give specific direction for conducting the work in an orderly manner. By these devices and by the including in each chapter of contents regarding machinery type, parts, and adjustments, the author has sought to assist vocational pupils in acquiring the ability necessary to maintain and repair machinery on the home farm or on the farms where they are employed. The book is divided into two parts. The first part consists of ten chapters on plows, harrows, grain drills and seeders, corn planters, cultivators, hoers, grain binders, manure spreaders, potato planters and diggers, and threshing machines. There are five chapters in part two on tractors, tractor carburetors, magnetos and ignition, repairing, and locating tractor troubles.

Termites and Termite Control, edited by *C. A. Kofoid, S. F. Light, A. C. Horner, Merle Randall, W. B. Herms*, and *Earl E. Bowe*. University of California Press, Berkeley, 1934. Cloth, 6x9½ in, 734 pp, 182 figs, bibl, $4.00 (paper), $5.00 (cloth), carriage extra (weight 3 lb). A report of the Termite Investigation Committee. In brief it is a discussion of the biology of termites, and an account of the termites of the United States, Mexico, the Canal Zone, the West Indies, Hawaii, and the Philippine Islands, with recommendations for the prevention and control of termite damage by methods of construction and the use of chemically treated and unpalatable woods. The report is a notable example of what can be accomplished when scientists, engineers,

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## EMPLOYMENT BULLETIN

**An employment service is conducted by the American Society of Agricultural Engineers for the special benefit of its members. Only Society members in good standing are privileged to insert notices in the "Men Available" section of this bulletin, and to apply for positions advertised in the "Positions Open" section. Non-members as well as members, seeking men to fill positions, for which members of the Society would be logical candidates, are privileged to insert notices in the "Positions Open" section and to be referred to persons listed in the "Men Available" section. Notices in both the "Men Available" and "Positions Open" sections will be inserted for one month only and will thereafter be discontinued, unless additional insertions are requested.**

### Men Available

ELECTRICAL ENGINEER with B.S., M.S. E.E. degrees in electrical engineering from University of Delaware (1925, 1929, and 1933), desires employment (1) in rural electrification research with a college, (2) in development and engineering work with a manufacturer developing and building equipment for the rural trade, or (3) commercial work with the rural service department of a power company. Experience: Worked and lived on a farm; 1½ years in engineering test work for General Electric Co.; 3 years teaching junior and senior electrical engineering subjects at the University of Delaware. Employed since 1929 as electrical engineer doing research and development work for the National Rural Electric Project. Will go anywhere. Available immediately. MA-233

AGRICULTURAL ENGINEER, with B.S. degree from the University of Wisconsin (1927) and a M.S. degree in agricultural engineering from Iowa State College (1933), desires employment (1) in the educational field as an instructor or extension worker, (2) as a research worker with preference in farm buildings, or (3) as a farm manager. Lacking only residential requirements for B.S. degree in education. Earned all college educational expenses. Reared on a large Wisconsin dairy farm. Three years' milking machine experience. Practical carpentry experience. Eighteen months of machine shop experience. Employed three months as a student trainee in assembling, repairing, and testing of farm tractors. Terracing and drainage experience. Twelve years' teaching experience, including five years as instructor in agricultural engineering at the University of Tennessee. Age 35. MA-244

## Literature Received

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and business men cooperate in an effort to solve a problem involving the public good. It treats the termite problem more exhaustively than any scientific treatise hitherto published, yet it is written in simple, non-technical language that the layman can readily understand. The destructive habits of termites are faithfully described, including the habits of eleven newly discovered species in California, and the question of effective means for the extermination and control of these insects is thoroughly discussed for the benefit of anyone using wood for building purposes in temperate and tropical countries. The immense amount of human experience and patience and labor that have gone into the gathering of the material for this report is immediately apparent from the table of contents. The book is intended primarily for biologists, architects, engineers, contractors, building inspectors, and users of wood. While thousands of dollars have been expended upon the necessary research and preparation of the material of this volume, none of this expense has been added to the publication cost.

HORTUS, by *Dr. L. H. Bailey* and *Ethel Zoe Bailey*. The Macmillan Company, New York, N. Y. Fabrikoid binding, 6¾x10 in, 632 pp, 35 illus, $5.00. This is the famous concise dictionary of North American plants which experts have proclaimed indispensable. It is a ready reference handbook for all who have occasion to use information about plants. It gives brief description, correct botanical and common names, and notes on culture and propagation for every group of plants known to be in common cultivation in the United States and Canada. It is useful alike to gardeners, growers, dealers, propagators, landscape architects, botanists, and students. It is an authority on cultural methods, hardiness of plants, special kinds of horticulture, uses of plants, soil requirements, transplanting, propagation methods, scientific and common names. It contains 5,290 separate articles, including plant names, definitions, vernacular names, and cross references. A total of 2,519 genera are described.

TIMKEN ENGINEERING JOURNAL. A new 266-page, loose-leaf book of general information on the various types of Timken bearings published by The Timken Roller Bearing Co., Canton, Ohio. It differs materially from previous editions since new load ratings have been established conforming to the fatigue life of the bearings. An explanation of these ratings along with the methods of calculating loads and selecting bearings comprises one section. This is followed by a statistical presentation of the bearings available in the various types. These tables have been arranged uniformly by cone bore with the smallest bores shown first. In the single-row group are included the standard or conventional bearings, the tapered-bore, steep-angle, keyway cone, flanged-cup, S.A.E. standard and airplane series. The two-row assemblies include the two-row self-contained bearings; the two-row, double-cone, single cups, both in the wide and narrow series. In the same group will be found the tapered-bore cones, with and without pullers, and the slotted-cone bearing. Following the last-named unit are the double-cup bearings, that is, the assemblies in which two standard cones are assembled into a double cup to form a unit, and the N.A. group. Both of these are divided into the regular and steep-angle series. Another tabulation appears here, consisting of a type of bearing very similar to the N.A. assemblies; the cone, however, consists of a single piece, the cups being held apart and the correct bearing set-up maintained through the use of a split spacer ring inserted between the cups. With this spacer in place the entire assembly becomes a complete unit. The four-row group consists of two tabulations, those with cone spacer pilots and those without. The former is recommended for those applications which require a loosely fitted cone on the shaft and the latter those with a tight fit. Following the tabulations just indicated will be found the "T" types or flat thrust bearings and the steering gear type bearings. The next two hundred odd pages comprise the dimension sheet section. The illustrations in this division are to scale and accurate to 0.01 in. This permits the draftsman to use them to trace the bearing in the proper position on his drawing either in full or half size, as both sizes are given. In the application of Timken bearings certain miscellaneous parts are frequently needed and the section immediately following the dimension sheets covers shims, nuts, tubes, washers, cotter pins, and several types of closures. The success of a Timken bearing application depends not only on the selection of the proper bearing but also on the observance of certain basic principles. These are covered thoroughly in the section on mounting. Shaft and housing design, typical mountings of single, double, and quadruple assemblies, closures, fitting tolerances for both cups and cones, assembly methods, data on lubrication and a description of the Timken wear and lubricant tester concludes the book.

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